ENVIRONMENTAL IMPACT ASSESSMENT FOR THE PROPOSED NUCLEAR POWER STATION ('NUCLEAR 1') AND ASSOCIATED INFRASTRUCTURE

Air Quality Impact and Climatology Assessment Study

August 2015

Prepared by: Airshed Planning Professionals (Pty) Ltd

Prepared for: GIBB Pty Ltd

On behalf of: Eskom Holdings Ltd

AIRSHED PLANNING PROFESSIONALS (Pty) Ltd
Reg. No.: 2002/023269/07

30 Smuts Drive
HALFWAY GARDENS
MIDRAND
P O BOX 5260
1685 HALFWAY HOUSE

TEL+27 (0)11 805 1940
FAX+27 (0)11 805 7010
e-mail: mail@airshed.co.za

3 August 2015

DECLARATION OF INDEPENDENCE

I, _***Lucian Willem Burger***_ as duly authorised representative of _***Airshed Planning Professionals (Pty) Ltd***_, hereby confirm my independence (as well as that of _ ***Airshed Planning Professionals (Pty) Ltd***_ as a specialist and declare that neither I nor _ ***Airshed Planning Professionals (Pty) Ltd***_ have any interest, be it business, financial, personal or other, in any proposed activity, application or appeal in respect of which Arcus GIBB was appointed as environmental assessment practitioner in terms of the National Environmental Management Act, 1998 (Act No. 107 of 1998), other than fair remuneration for work performed, specifically in connection with the Environmental Impact Assessment for the proposed conventional nuclear power station (‘Nuclear 1’). I further declare that I am confident in the results of the studies undertaken and conclusions drawn as a result of it – as is described in my attached report.

____

Full Name: Lucian Willem Burger

Title / Position: Managing Director

Qualification(s): PhD (Natal), MSc Eng (chem.), BSc Eng (Chem)

Experience (years/ months): 27 years

Registration(s): South African Institute of Chemical Engineers (*Fellow: No. 4533*)

EXECUTIVE SUMMARY

Eskom proposes to construct a nuclear power station in South Africa with a power generation capacity of up to 4 000 MWe. In this EIA, the project is known as Nuclear-1, which includes the assessment of three sites. As a preliminary indication of the schedule, it was given that site access and terrace preparation for Nuclear-1 is proposed for January 2017, and would continue for 6-12 months. Construction of the nuclear power station would last for 7-9 years

The proposed sites for these power stations include:

- Duynefontein (Western Cape) located adjacent to the existing Koeberg Power Station, Cape Town;
- Bantamsklip (Western Cape) located 10 km south-east of Pearly Beach; and
- Thyspunt (Eastern Cape) located west of Port Elizabeth and approximately 15 km west of Cape St. Francis.

The Scoping Phase of this Environmental Impact Assessment (EIA) process has recommended that the two sites in the Northern Cape (Brazil and Schulpfontein) be excluded from further investigation during the EIA phase.

Eskom proposes to utilise Pressurised Water Reactor (PWR) technology. However, a final vendor specific plant design has not been decided on as yet. This assessment was therefore based on a generic nuclear power station, with atmospheric release information that provided an envelope of different reactor designs. In all cases, the worst-case impacts were assessed. The assessment therefore includes the maximum radionuclide emission from the nuclear power station during routine operation for its entire lifetime and design basis accident (DBA[1]) scenarios based on different reactor design technologies, which are being considered by Eskom.

AIRSHED PLANNING PROFESSIONALS (Pty) Ltd was appointed by ARCUS GIBB (Pty) Ltd to undertake an Air Quality Impact and Climatology Assessment for the proposed construction, operation and decommissioning of the nuclear power station and associated infrastructure.

METHODOLOGY

The main objective of the study was to determine the potential air pollution impacts associated with the construction, operation and decommission of the proposed nuclear power station on the surrounding environment. To accomplish this, the first step was to establish the baseline conditions of the proposed three sites through measurement of local meteorology. The next step was to determine all air emissions which are expected to result during the different phases. Whilst great care was taken to estimate emissions expected during the construction phase, it is anticipated that some minor differences may eventually exist with the final construction plan. The impact during the decommissioning phase was qualitatively evaluated using a proforma decommissioning plan. The atmospheric dispersion of emissions of all potential air pollutants during the operational phase was included in the assessment. These included non-radionuclides and radioactive emissions. Air concentrations and fallout rates were simulated using meteorological data recorded on site[2] and from the closest South African Weather

[1] A postulated accident that a nuclear facility must be designed and built to withstand without loss to the systems, structures, and components necessary to assure public health and safety. Design Basis Accidents, which could include pipe ruptures, component failure, etc. must be controlled by the safety facilities in such a way that effects on the environment are kept below the specified planning values of the NNR, i.e. the effective dose to a worker or members of the public is less than 50 mSv.

[2] Onsite meteorological data at Thyspunt and Bantamsklip was only available for a few months at the outset of the impact assessment. On subsequent review of the assessment, more than a year's onsite

Services (SAWS) meteorological stations with adequate historical data. For non-radioactive air releases, ambient air quality guidelines were used to compare against predicted concentrations, which serve to provide a screening health risk[3]. The impact of radionuclides was assessed in a similar fashion as non-radioactive substances, i.e. comparison to a "dose limit". However, the predicted nuclide activities ("concentrations") and surface deposition rates were first converted to an effective dose[4]. The study focused only on inhalation, immersion in a cloud and irradiation from surface soils. The ingestion pathway (water and food) is dealt with in the overall health risk study using the air concentration and deposition rates results derived from this study.

For the purposes of this assessment, a 40 km by 40 km study area was defined for the local dispersion calculations. No specific study area was defined for long-range transport since these were based on the distances typically travelled by the pollutants over a three-day period.

ASSUMPTIONS AND LIMITATIONS

The lack of knowing the specific vendor for the nuclear power station is considered to be a gap. This is specifically important with regards to the radionuclide emission source term. However, in order to account for the possible radionuclide emissions from the proposed nuclear power station, the source terms from two candidate vendors were included in the assessment. These source terms provides an envelope of different reactor designs. These emissions included both normal and upset conditions. The assessment was therefore based on the most conservative results from these two vendors. It should be noted that in order to comply with NNR requirements, the proposed nuclear power station will have to remain within the emission levels stipulated in its licence.

Catastrophic incidents were not part of the plan of study for the assessment since these incidents are within the jurisdiction and mandate of the NNR. The NNR will evaluate the safety case for the proposed nuclear power station to determine compliance with the requirements contained in Government Notice R388 of 28 April 2006, "Safety Standards and Regulatory Practices". The NNR process has not start yet, but will follow after the specific PWR vendor has been selected as part of the procurement process . Thus accident scenarios have not been expressly dealt with in this assessment.

Although the relatively short, one-year period of meteorological data recorded at Thyspunt and Bantamsklip may also be regarded as a limitation to the dispersion modelling results, a comparison of the onsite data with the longer records at Cape St. Francis and Hermanus, respectively, indicate that the prevailing meteorological parameters (i.e. wind speed, wind direction, rainfall and ambient air temperatures) are comparable and result in similar conclusions. Although a more extended onsite monitoring period would provide slight adjustments to the results, it is not anticipated that the conclusions, given below, would change with any significance.

Decommissioning plans for PWRs are similar and consequently the decommissioning plan of Koeberg was use in this assessment. Furthermore, the impact would have to comply with the dose limits stipulated by the National Nuclear Regulator (NNR).

---

meteorological data became available and a comparison to the SAWS data revealed small differences, which would not change the conclusions of the assessment.

[3] The air concentrations and deposition of non-radionuclide pollutants were compared to health risk limits developed by international institutions, such as the World Health Organisation (WHO), to represent safe levels below which no health risk effects are observed. Exceedances of a limit would flag for additional mitigation of emissions.

[4] Effective dose is an estimate of the effect that a non-uniform radiation dose has on a human. (The unit for effective dose is the Sievert (Sv)). Dose conversion coefficients ($Sv/(Bq/m^3)$) obtained from the International Commission on Radiological Protection (ICRP), as contained in ICPR Publication 72 were used. The ICRP 72 is the latest revision. These dose conversion coefficients allow the calculation of age-dependent doses to the members of the public from the intake of and exposure to radionuclides. Dose conversion coefficients are available for all radionuclides.

Whilst the study included baseline air quality monitoring for non-radionuclides, a radiological baseline study was not included. The NNR requires that a baseline monitoring campaign of radionuclides be conducted prior to construction. Furthermore, the dose limits stipulated by the NNR applies to the incremental dose calculated for the proposed nuclear power station. The conclusions would therefore not change, even once the natural radioactivity has been established at the three sites.

This assessment utilised air quality limits which have been given by the Department of Environmental Affairs (DEA) for non-radionuclide emissions and by the NNR for radionuclide emissions, respectively. The assessment of health risks is therefore considered to be at a screening level. The results from this assessment will be used as input into the Health Risk Assessment for this EIA which will be a qualitative assessment of the impact of radionuclides on human health and ecology.

Although a comprehensive sensitivity analysis of the dispersion model was not completed, the most important features were tested, which included the treatment of land-sea interaction and topography. In all cases, the most conservative option was selected to complete the assessment. A more detailed comprehensive evaluation of the quality of data and model sensitivities will be part of the application for a licence from the NNR.

CONCLUSIONS

The predicted impacts would be similar at all three sites. Furthermore, based on the predicted impacts of both non-radioactive and radionuclide air pollution, the assessment concludes that none of the sites need to be discarded for the proposed nuclear power station.

Specific mitigation is recommended during the construction phase only. Due to the predicted low impact of radionuclide emissions under normal operation, no additional mitigation would be required for radionuclide emissions.

Construction Phase

The sources of impacts during construction would be fugitive dust emissions from general construction activities (clearance, excavation, scraping, road surfaces etc) and emissions emanating from vehicles and equipment. Construction phase impacts will have a HIGH *significance* if no or limited mitigation measures are applied. This impact can be reduced to LOW *significance* if unpaved roads are surfaced (i.e. tarred) and with implementation of an air quality management plan.

Operational Phase

Potential sources of non-radioactive air emissions during the operational phase include:

- Carbon, sulfur and nitrogen oxides in the exhaust gases from engines of the backup electricity generators;
- Formaldehyde and carbon monoxide emitted by the insulation when installations go back into operation after servicing; and
- Ammonia discharged as the temperature rises in the steam generators during start-up.

The predicted impacts of these non-radiological pollutants were predicted to be very low when compared to human health risk and vegetation impact criteria.

During normal operation, trace quantities of radiological materials will be released to the environment. Ignoring the ingestion pathway, the predicted effective dose from these pathways indicates LOW *significance*. This rating applies to all three sites.

The predicted impacts of non-radioactive emissions during the operational phase at Bantamsklip and Thyspunt were shown to have a LOW *significance*. Currently, no industrial, commercial or significant residential developments exist in these two areas. This was confirmed through a three-month sampling campaign during which ambient air sulfur dioxide and nitrogen dioxide concentration levels were measured. The cumulative air pollution impact would therefore essentially only be that of the proposed nuclear power station.

In contrast, Duynefontein is located in an area where there is the potential for slightly elevated air pollution levels due to the proximity to Cape Town. However, based on background measurements, the impact of other air pollution sources[5] in the vicinity of Duynefontein was shown to be limited. The predicted cumulative impact of air pollution at the Duynefontein site is considered to be of LOW *significance*.

The dispersion simulations included a number of identified DBA. The predicted highest whole body dose at 1 km downwind from the nuclear power station following such accidental releases was shown to be below the maximum acceptable limit of 50 mSv for a single event, as stipulated by the NNR.

Decommissioning Phase

The exposure to radiation, based on the decommissioning plan developed for Koeberg, be kept to a minimum and below the required dose stipulated by the National Nuclear Regulator (NNR). Since these dose limits are based on safe exposure levels, it is expected that the radiation exposure during commissioning would be low. The plan consists of six phases. At the end of the last phase (*Phase 6*), the sub-surface radionuclide concentrations would again be verified to meet site release requirements.

"No-Go" Option

Duynefontein Site

Without the proposed nuclear power station at the Duynefontein site, the "no-go" option would be the same as the current air quality impact, which is considered to be of LOW significance for non-radioactive compounds and MEDIUM significance for radionuclide emissions.

Bantamsklip and Thyspunt Sites

The current air quality at the Bantamsklip site is regarded very clean with regards to non-radioactive criteria pollutants, such as oxides of nitrogen, sulphur dioxide and carbon monoxide. Any alternative developments on the site which would increase vehicle numbers, introduce combustion sources (ovens, boilers, heaters, etc.) or human population could have the potential of increasing the levels of these criteria pollutants. The significance depends on the alternative options, and could result in a HIGH significance.

Since the current baseline dose at these two sites are not known, it is not quantitatively possible to provide an accurate "no-go" impact rating for radioactivity. Given the low dose limits set by the NNR, normal emission would result in dose levels within naturally occurring radiation levels. However, in the event of an accidental release, it is expected that the dose would be above the naturally occurring radioactivity at the site and as such, unless radioactive material is used in any alternative developments, the radio nuclear impact of the "no-go" option would be rated lower.

---

[5] No industrial air pollution sources other than the Koeberg Nuclear Power Station exist in the immediate Duynefontein area. Industrial processes are present at Atlantis (Open Cycle Gas Turbine Power Station, brickworks and other smaller commercial activities) about 9 km northeast, landfill operations at Vissershok (5 km southeast) and a petroleum refinery (approximately 21 km south-southeast). Vehicles along the main roads (e.g. R27) and nearby residential areas also contribute to the airshed, especially oxides of nitrogen. Unfortunately, no historical air quality monitoring data is available for Duynefontein. However a relatively short, three-monthly sulfur dioxide and nitrogen dioxide air sampling campaign was conducted from March to May 2009. These data indicated low sulfur dioxide and nitrogen dioxide concentrations.

RECOMMENDATIONS

- The predicted impacts of unmitigated emissions during the construction phase were shown to have a HIGH significance.
    - A comprehensive list of recommendations has been provided in Section 5.2.1.
    - This impact can be reduced to LOW significance with management plans and emission controls in place.
    - An emission minimisation plan is regarded essential in the situation where construction activities are conducted very close to residential and other sensitive receptors.
    - The most significant source (between 80% and 90%) of fugitive dust emissions was shown to be wheel entrainment on unpaved roads. It is, therefore, recommended to have the initial focus on the reduction of emissions from road surfaces. This can be achieved through regular watering of unpaved surfaces, applying chemical dust suppressants, or most preferably, tarring of road surfaces.
    - In areas where tarring is not a practical option the management plan should have, as a minimum, watering schedules of unpaved roads and other activities that could be mitigated with water sprays.
    - In addition to road surface treatment, it is recommended to utilise the construction mitigation management checklist given in Appendix D, or a suitably modified version thereof.
- The recommended air quality monitoring programme provided in Section 5.2.1 should preferably be initiated a year prior to construction. This would provide an adequate baseline air concentration trend which would incorporate all seasons. This programme must include both non-radionuclide and radionuclide compounds (as stipulated by the NNR);
- No additional mitigation measures are required for routine operational emissions of radionuclides. However, once the final reactor technology has been decided, Eskom needs to confirm that the emissions from the selected technology conforms to the envelope used in this assessment and that such emissions can be maintained throughout the nuclear power station's lifecycle. This includes a thorough assessment of the reliability and maintenance of the high efficiency particulate air (HEPA) filters which would be used to control radiological air emissions from the nuclear power station;
- Similarly, the successful technology supplier must illustrate how incidental and accidental releases would conform to the NNR's requirements and how these would be kept As Low As Reasonably Achievable (ALARA);
- The impact during the decommissioning phase was qualitatively assessed based on the assumption that the decommissioning plan would be the same as that developed for the Koeberg nuclear power station. A site-specific decommissioning plan must be developed according to the most recent requirements stipulated by the NNR.
- It is recommended to ensure that the emissions from the backup power generators perform according to the vendor specifications, which the assessment was based on. Although continuous emissions monitoring (CEM) would be preferred for particulates and oxides of nitrogen, regular stack sampling campaigns would be adequate given the intermittent nature of operation. It is recommended that the first three isokinetic sampling campaigns should also include sulfur dioxide analysis.
- Air dispersion modelling must be repeated using the source terms for normal and upset emissions of the successful vendor and onsite meteorological data prior to construction of the nuclear power station. The simulations must be repeated for both non-nuclear and radionuclide air emissions. Furthermore, the methodology for calculating the dose must be done according to the latest international standards and NNR requirements.

ENVIRONMENTAL IMPACT ASSESSMENT FOR THE PROPOSED NUCLEAR POWER STATION ('NUCLEAR-1') and ASSOCIATED INFRASTRUCTURE

CONTENTS

TABLES

FIGURES

ABBREVIATIONS

AERMIC	AMS/EPA Regulatory Model Improvement Committee
AERMOD	AERMIC dispersion model
AERMAP	AERMOD terrain pre-processor
AERMET	AERMOD meteorological pre-processor
APCS	Air Pollution Control System
AQGs	Air Quality Guidelines
BMP	best management practices
Bq	becquerel(s)
BWR	boiling water reactor
C	Celsius
CEDE	committed effective dose equivalent
CFR	Code of Federal Regulations
cm	centimetre(s)
CO	Carbon monoxide
CO_2	Carbon dioxide
d	day
DBA	design-basis accident
DEA	Department of Environmental Affairs (previously the Department of Environmental Affairs and Tourism)
DME	Department of Minerals and Energy
DWAF	Department of Water Affairs and Forestry
EC	European Community
EIA	Environmental Impact Assessment
EMS	Environmental Management System
EPA	U.S. Environmental Protection Agency
ESE	east-southeast
ha	hectare(s)
HC	Hydrocarbon
HLW	high-level waste
HP	High Pressure
HWR	Heavy Water Reactors
hr	hour(s)
IAEA	International Atomic Energy Agency
ICRP	International Commission on Radiological Protection
IPF	Inner perimeter fence: 0.6 km to 1 km
ISCST	Industrial Sources Complex Short-Term Model
IT	Interim Targets
kg	kilogram(s)
km	kilometre(s)
kV	kilovolt(s)
kWh	kilowatt hour(s)
L	litre(s)
LLW	low-level waste
LPZ	low population zone
LWR	light-water reactor
m	metre(s)
m/s	metre(s) per second
MSL	mean sea level
mSv	millisievert(s)
µSv	microsievert(s)
MW	megawatt(s)

MWe	megawatt(s)-electric
MWt	megawatt(s)-thermal
MWh	megawatt hour(s)
NA	not applicable
NCDC	National Climatic Data Centre
NCRP	National Council on Radiation Protection and Measurements
NEMA	National Environmental Management Act
NNE	north-northeast
NOAA	National Oceanographic and Atmospheric Administration
NO	Nitrous oxide
NO_2	Nitrogen dioxide
NOx	Oxides of nitrogen
OA	Options Analysis
PAH	Polycyclic aromatic hydrocarbons
PBMR	pebble bed modular reactor
PEB	Public exclusion boundary:1.5 km to 2.9 km
PPE	plant parameter envelope
ppm	parts per million
PM2.5	Particulate matter with diameter of 2.5 µm
PM10	Particulate matter with diameter of 10 µm or less
PWR	pressurised water reactor
radwaste	radio-active waste
RCIC	reactor core isolation cooling
REMP	radiological environmental monitoring programme
s	second
SA	South African
SABS	South African Bureau of Standards
SANS	South African National Standards
SAWS	South African Weather Services
SO_2	Sulfur dioxide
SOx	Sulfur oxide(s)
SSR	Site Safety Report
SSE	south-southeast
Sv	sievert(s)
t	metric ton(s) (or tonne[s])
TLD	Thermoluminescent dosimeter (a TLD measures ionizing radiation exposure)
TSP	Total Suspended Particulates
UK	United Kingdom
USA	United States of America
US EPA	United States Environmental Protection Agency
WB	World Bank
WHO	World Health Organisation
yr	year(s)
µ	Micro

1 INTRODUCTION

1.1 Background

AIRSHED PLANNING PROFESSIONALS (Pty) Ltd has been appointed by ARCUS GIBB (Pty) Ltd to undertake an Air Quality Impact and Climatology Assessment for the proposed construction and operation of the nuclear power station. Five sites were originally identified for consideration and these are located in the Northern, Eastern and Western Cape Provinces, as shown (Figure 1-1):

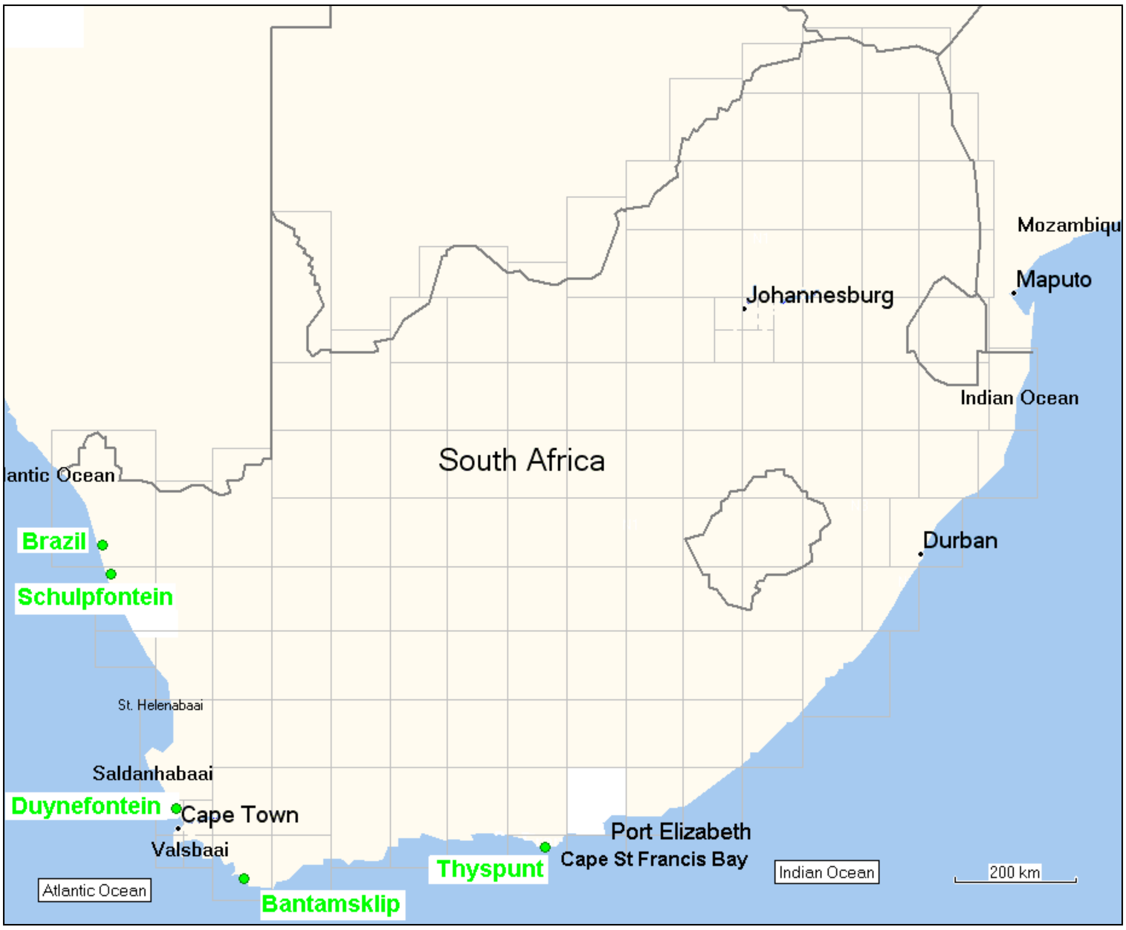


Figure 1-1: Locations of five alternative sites for Nuclear-1

The Scoping Phase of this EIA process recommended that the two sites in the Northern Cape (Brazil and Schulpfontein) be excluded from further investigation. Their exclusion was based on the fact that these alternative sites would not constitute reasonable and/or feasible site alternatives for Nuclear-1 based on limited local demand and the lack of existing electricity transmission corridors associated with these sites.

The other three sites, which form part of this investigation, include:

- Duynefontein (Western Cape) located adjacent to the existing Koeberg Power Station, Cape Town;
- Bantamsklip (Western Cape) located 10 km south-east of Pearly Beach; and

- Thyspunt (Eastern Cape) located west of Port Elizabeth and approximately 15 km west of Cape St. Francis.

This assessment includes the impact due to the construction, operation and decommissioning phases of the proposed nuclear power station. This assessment forms an integral part of the overall Environmental Impact Assessment (EIA) and Environmental Management Plan (EMP).

The preliminary schedule indicates that site access and terrace preparation for Nuclear-1 is proposed for January 2013, and would continue for 6-12 months. Construction of the nuclear power station would last for 7-9 years, with a proposed start of construction in July 2012.

1.1.1 Nuclear Power Technologies

Several Nuclear Power Plant types are used internationally for energy generation and are usually classified based on the main features of the reactor applied in them. The main power plant reactor types currently in operation in the world are:

- Light Water Reactors (LWR);
- Heavy Water Reactors (HWR); and
- New Generation Reactors (Generation IV).

The Light Water Reactor (LWR) category has been subdivided into the Pressurised Water Reactor (PWR) and Boiling Water Reactor (BWR). LWRs utilise ordinary water ("light water", H_2O) to moderate and cool the reactors. HWR use "heavy water" or deuterium oxide (D_2O) as a neutron moderator and coolant.

The Eskom study to include nuclear power in its generation mix converged on Generation III / III+ reactors; *viz.* LWR and HWR. Generation IV reactors were not considered as they are still in developmental stages. Furthermore, Eskom proposes to employ LWR and more specifically, Pressurised Water Reactor (PWR) technology.

The PWR is the most widespread reactor type used in the world. It provides about 64 % of the total power of the current global operating nuclear power plants. A primary characteristic of PWRs is a pressuriser, which is a specialised pressure vessel. Most commercial PWRs and naval reactors use pressurisers. During normal operation, a pressuriser is partially filled with water and a steam "bubble" is maintained above it by heating the water with submerged heaters. The pressuriser is connected to the primary reactor pressure vessel (RPV) and the pressuriser "bubble" provides an expansion space for changes in water volume in the reactor. This arrangement also provides a means of pressure control for the reactor, by increasing or decreasing the steam pressure in the pressuriser using the pressuriser heaters.

Cooling water circulates in two or more loops, which are fully separated from one another. The fuel in pressurised water reactors is usually low enriched uranium oxide (LEU), although in some cases uranium and plutonium oxide mixture (MOX) is used. In today's PWRs, the primary pressure usually ranges from 120 bar to 160 bar, while the outlet temperature of coolant is 300ºC to 320°C.

The plant types found under the PWR category include:

- EPR;
- AP1000;

- RSA1000; and
- VVER1000.

1.1.2 Legislative Framework

The legal basis for utilisation of nuclear energy in South Africa is established by the National Nuclear Regulator Act, 1999 (Act No. 47 of 1999) (Section 20, NNR 1999). This requires persons who may wish to site, construct, operate, decontaminate or decommission a nuclear installation, such as a nuclear power station, to perform these activities under the authority of a nuclear installation licence.

For licensing of the nuclear power station, it must be demonstrated that the Basic Licensing Requirements (BLR) formulated in the Regulations on Safety Standards and Regulatory Practices published as Regulation No. 388 dated 28 April 2006 are met. In this regulation the accepted public and worker exposure dose limits to radioactive material is provided.

The NNR provides guidance on acceptable atmospheric dispersion models in their Guideline on the Assessment of Radiation Hazards to Members of the Public from Mining and Mineral Processing Facilities (LG-1032) (NNR, 1997). The guidance essentially adopted the US Environmental Protection Agency's dispersion models used for regulatory purposes. They include the following models:

- Industrial Source Complex Model (ISC model);
- Fugitive Dust Model (FDM);
- Complex Terrain Dispersion Model (CTDM);
- Rough Terrain Dispersion Model (RTDM); and
- INPUFF.

At the time of the investigation, the use of specific dispersion models for the assessment of an nuclear power station has not been dealt with by the NNR. In its absence, it will be assumed that the models listed above would similarly be acceptable for the assessment of emissions from the nuclear power station.

The International Basic Safety Standards for Protection against Ionising Radiation and for the Safety of Radiation Sources (BSS) (IAEA, 1996) establishes basic and detailed requirements for protection against the risks associated with exposure to radiation and for the safety of radiation sources that may deliver such exposure. The standards are based primarily on the 1990 Recommendations of the International Commission on Radiological Protection (ICRP) (ICRP, 1990) and other International Atomic Energy Agency (IAEA) Safety Series publications. The BSS (IAEA, 1996) place requirements on both the Regulatory Authority and on the legal person responsible for a source. These requirements and the procedures required to fulfil them are outlined in more detail by the IAEA (2000).

The regulation of conventional air pollution, as opposed to the impact of airborne radionuclides, has until recently been regulated by the Atmospheric Pollution Prevention Act, 1965 (APPA) (Act No. 45 of 1965, Second Schedule). However, the APPA has subsequently (11 September 2005) been replaced by National Environmental Management: Air Quality Act, 2004 (NEM-AQA) (Act No. 39 of 2004).

The aim of NEM-AQA is to reform the law regulating air quality in order to protect and enhance the quality of air in the Republic, taking into account the need for sustainable development, to provide for national norms and standards regulating air quality monitoring, management and control by all spheres of government; for specific air quality measures; and for matters incidental thereto.

The approach of the NEM-AQA is to shift the focus to the receiving environment and to decentralise responsibilities to provincial and local government. This would require baseline air quality characterisation studies to be conducted for regions and provinces to identify areas and pollutants of concern. All sources within a region would have to be addressed and if identified as a main contributing source would be expected to develop and implement emission reduction strategies. Standardisation of various aspects of air quality management would be required including methodologies on monitoring, modelling, management and reporting. Public participation is a requirement of the impending act which would require industries to follow a transparent management approach. The NEM-AQA makes provision for the setting of ambient air quality standards and emission limits on National level, which provides the objective for air quality management. More stringent ambient standards may be implemented by provincial and metropolitan authorities.

The NEM-AQA therefore commits the country to pollution prevention and air quality improvement and maintenance coincident with socio-economic development and not at the expense of such development. The objective of this Act is given as the protection of the environment by providing reasonable measures for:

- the protection and enhancement of the quality of air in the country;
- the prevention of air pollution and ecological degradation; and
- securing ecologically sustainable development while promoting justifiable economic and social development.

The Department of Environmental Affairs (DEA) published the National Ambient Air Quality Standards (NAAQS) in the Government Gazette on the 24th of December 2009. These standards were essentially based on the limit values developed originally by a technical committee and three working groups under the auspices of the South African Bureau of Standards (SABS). SABS was engaged to assist the DEA in the facilitation of ambient air quality standards for criteria pollutants. Standards were determined based on international best practice for airborne particulates (i.e. particulate matter with aerodynamic diameter of 10 µm or less PM10), dustfall, suphur dioxide (SO_2), nitrogen dioxide (NO_2), ozone (O_3), carbon monoxide (CO), lead (Pb) and benzene. These standards were first published for comment in the Government Gazette on 9 June 2007 with the revised standards published for comment on 13 March 2009. The final standards were published on 24 December 2009.

1.2 Study Approach

Potential air emissions from the proposed nuclear power station would be both radioactive and non-radioactive. Radioactive emissions would be produced by activities associated either directly or indirectly with operating and maintaining the reactor, and ultimately, from decommissioning the plant.

Non-radioactive emissions would occur during construction, operation and decommissioning phases of the project. Non-radioactive air emissions include airborne particulates, primarily during construction and decommissioning, and combustion gases from standby diesel generators.

The site characteristics that could influence the impact of the nuclear power station on the environment through air exposure and surface deposition of the air emissions include the local and large-scale weather conditions, topographical features and land use.

The following discussion provides a summary of the approach and methodology, the available information sources, assumptions and limitations of study.

1.2.1 Terms of Reference

The study has been based on the following scope of work requested by ARCUS GIBB.

- Assess current conditions with respect to air quality using available air quality data otherwise qualitatively, population distribution and general atmospheric characteristics, especially prevailing wind directions (including meso- and micro meteorological characteristics of the site and region);
- Review of previously completed reports and other available data;
- Describe the local meteorological parameters, important for the prediction of future air pollution impacts;
- Provide a general description of the dispersion potential;
- The above must include the collection of and / or development of parameters that can be justified and used to predict atmospheric dispersion of materials released from the proposed facility;
- Describe the current air quality in the area using available air quality data otherwise qualitatively;
- List other sources of air pollution that may contribute to the area of impact;
- Identify sensitive receptors (e.g. residential areas) and potential impacts on air from both non-radioactive and radioactive air emissions;
- The receptors to be identified should include ecological (non human) as well as human receptors;
- Establish an emissions inventory, conduct dispersion simulations and health risk impacts through cross-reference to the human health risk specialist assessment study;
- Detailed analyses of the atmospheric dispersion potential, current air quality (using available air quality data) and syntheses of legal and health criteria;
- Assess the contribution of the atmospheric pathway to a human health impact through cross-reference to the human health risk specialist assessment study;
- Assess the intensity of the expected impacts, based on existing information along the routes;
- Simulate emissions using NNR approved atmospheric dispersion model/s;
- Compare non-radioactive air concentrations against the South African standards for criteria pollutants, and to internationally accepted guidelines for non-criteria pollutants;
- Determination of current and future (proposed nuclear power station) compliance to South African air emissions legal requirements;
- Address the assumption that insignificant amounts of radionuclides would be released during the decommissioning and closure phases.
- Detailed literature survey and information gathering session for all local climate data for the sites and surrounding areas;
- Describe the status quo of the climate for the various site alternatives;

- Detailed assessment of the radionuclide content of ventings and purgings; decay periods involved; whether or not they could be cumulative; types of radiation predicted; and potential impact on surrounding communities;
- Assessment of potential radionuclide emissions during malfunction or accident, to determine time frames and significance of risk;
- Detailed literature survey and information gathering session for all local climate data for the sites and surrounding areas;
- Describe the *status quo* of the climate for the various site alternatives;
- Predict the dispersal of any emissions from the site, under different archetypical large-scale wind fields;
- Model the trajectory of air parcels;
- Provide estimates of the probability of dispersal around each site, which must provide information regarding the expected radius and direction of dispersal;
- Assess the accuracy of these dispersal patterns;
- Predict likely scenarios in view of projected climatic changes and the associated implications for each site.

1.2.2 Methodological Overview

(a) Baseline Establishment

The main objective of the study is to determine the potential air pollution impacts associated with the construction, operation and decommission of the proposed nuclear power station on the surrounding environment. To accomplish this, the first step is to establish the baseline conditions of the proposed three sites, which requires knowledge on the following:

- existing air quality;
- other sources of air pollution;
- description of the receiving environment;
    - human settlements;
    - land use activities;
    - topographical features;
- local meteorological conditions; and
- large-scale circulation patterns.

The quantification of the existing air concentration levels in the area is achieved through the analysis of available air quality monitoring data and the calculation of air concentrations from current operations (e.g. Koeberg at the Duynefontein Site). The calculated impact from current operations requires the establishment of an emissions inventory for inclusion into a suitable atmospheric dispersion model. This procedure therefore requires the identification of all potential sources of air pollution and the type of pollutants to quantify and subsequently assess.

The accuracy of calculated air concentrations requires detailed meteorological data, which includes at least one year’s information. Such data must be representative of the atmospheric conditions at the point of release and provide adequate detail to extrapolate to other locations within the study area.

The wind and turbulence fields would also be affected by topography and nearby water bodies. It is therefore imperative to include topographical features and sea characteristics (i.e. location and sea temperatures) in the dispersion model.

(b) Predicted Impact

The impact assessment of the additional air pollution due to the proposed nuclear power station can be achieved through a similar establishment of the incremental emissions from the proposed nuclear power station and subsequent air concentration and deposition predictions using the same dispersion model.

Air emissions are expected to result during the construction, operational and decommission phases. The main pollutant of concern during construction would be airborne particulates. The likely sources of these air quality impacts would be fugitive dust emissions from general construction activities (e.g. clearance, excavation, scraping, road surfaces and material handling) and the potential for elevated ambient air quality levels caused by emissions emanating from transportation vehicles and equipment used by the workforce during the construction phase. The main impacts would be from inhalable particulates (i.e. particulates with aerodynamic diameter of 10 micron or less) and dust fallout (mainly of nuisance value). In order to complete a detailed impact assessment, each construction activity with associated equipment would be required. Detailed construction schedules and activities were used where possible. Exact locations of storage piles (e.g. topsoil) were not known, and these were assumed to be located nearby the construction site, but outside the footprint area. Pollutant emission rates were calculated using emission factors developed by the US Environmental Protection Agency (US EPA) for these activities. Windborne emissions due to erosion of exposed areas were also included.

During normal operation, small quantities of radiological materials are released to the environment. The type and amount of radionuclides (*source term*) provided by the respective designs would be used to calculate air concentration and deposition rates.

Potential sources of non-radioactive air emissions during the operational phase include:

- carbon, sulfur and nitrogen oxides in the exhaust gases from engines of the backup electricity generators;
- formaldehyde and carbon monoxide emitted by the insulation when installations go back into operation after servicing; and
- ammonia discharged as the temperature rises in the steam generators during start-up.

Although the dispersion of air pollutants was calculated for the entire modelling domain, specific attention was given to sensitive receptors (e.g. populated areas, agricultural activities, sensitive fauna and flora). The predicted air concentrations, deposition rates and in the case of radionuclides, effective dose isopleths[6] have been superimposed on base maps of the study areas.

The radionuclides[7] released during normal operation include tritium, carbon-14, iodine isotopes, noble gases and a small amount of other fission/activation products (mainly cobalt and caesium). Noble gases typically include krypton, xenon and argon.

[6] An isopleth is a contour line connecting points that have an equal air concentration (fallout rate or dose) value at a given time and spatial area.

[7] Although radionuclides are artificially produced in the reactor units they also occur naturally as trace elements in rocks and soils as a consequence of the "radioactive decay'' of uranium-238 (U-238) and thorium-232 (Th-232). This decay happens because radioactive atoms have too much energy, which is available to be imparted either to a newly-created radiation particle within the nucleus, or else to an atomic electron. When radioactive atoms release or transfer their extra energy, it is called decay. The

The main source of gaseous radioactive emissions during normal operation is the gaseous component arising within the coolant circuit. These gases are collected by the gaseous radio-active waste system (GRWS) and held for decay storage in the activated carbon bed delay system. This delay system includes a gas cooler, a moisture separator, an activated carbon-filled guard bed, and two activated carbon-filled delay beds. The effluent from the delay bed passes through a radiation monitor and discharges to the ventilation exhaust duct. The gaseous radio-active waste (radwaste) system is used intermittently. Most of the time during normal operation of the reactors, the gaseous radwaste system is inactive. When there is no waste gas inflow to the system, a small nitrogen gas flow is injected into the discharge line at the inlet of the discharge isolation valve. This nitrogen gas flow maintains the gaseous radwaste system at a positive pressure, preventing the ingress of air during periods of low waste gas flow.

Gaseous activity will also be present in the main process buildings, which are serviced by the heating, ventilation and air-conditioning (HVAC) systems. Discharges from these systems are via high level stacks located on the top of the reactor building and the radwaste building. There is provision for monitoring these discharges after filtration through high efficiency particulate air (HEPA) filters and, where appropriate, charcoal adsorption. There is also the possibility of tritium in the secondary circuit from minor leaks from the primary circuit. This is collected in the condenser air removal system. There are provisions for sampling and monitoring gaseous effluents at various points in the gaseous radwaste system.

The impact of radionuclides is assessed in a similar fashion as non-radioactive substances, i.e. comparison to a “dose limit”[8] and/or the application of cancer risk factors to individual nuclide concentrations and deposition rates. Furthermore, radionuclide exposure calculations require the summation of effective doses through all pathways, including inhalation, external radiation (i.e. immersion in a cloud containing radionuclides and irradiation from surface soils containing radionuclides) and ingestion. This study focuses only on inhalation, immersion in a cloud and irradiation from surface soils. The ingestion pathway (water and food) is dealt with in the overall health risk study using the air concentration and deposition rates results from this study.

The air pollution impact during the decommissioning phase could potentially include non-radioactive and radionuclide emissions. The former would be due to demolishing activities, operation of power generators and the latter due to residual radionuclide material.

For the purposes of this assessment, a 40 km by 40 km study area is defined for the local dispersion calculations. No specific study area is defined for long-range transport, since this is based on the distances typically travelled over a three-day period.

---

energy they release is called ionizing radiation, which may be alpha particles, beta particles, or gamma rays. This energy is transmitted through space or another medium in waves (e.g., x-rays or gamma rays) or particles (e.g., electrons or neutrons) and is capable of either directly or indirectly removing electrons from atoms, thereby creating ions, which are electrically charged atoms.

[8] Dose limit value of an ionizing radiation fixed by the legislator as a maximum to which a person may be exposed based on recommendations from scientific committees. Different dose limit values are fixed for different groups of persons. The effective dose for members of the public must not exceed a dose limit of 1 mSv/year.

(c) Impact Assessment Methodology

The assessment of radionuclides and non-radionuclides are carried out using slightly different approaches. Furthermore, the level of assessment can range from a comparison of predicted air concentrations with accepted screening values to conducting a detailed health risk assessment. In this study, the predicted impacts will be compared against screening values only, as described below.

For non-radioactive air releases, ambient air quality guidelines, emission limits and standards exist for all common pollutants, and include all the anticipated pollutants from the proposed nuclear power station. These criteria can be divided into "compliance" and "health risk" limits. The former consist of air quality values for the most common industrial air pollutants such as sulfur dioxide, nitrogen dioxide, carbon monoxide, benzene and inhalable particulates, which values have been stipulated by the DEA. Health risk criteria exist for a larger range of pollutants, and may either be used in simplistic comparisons (i.e. a threshold limit, health indices) or to estimate dosages and subsequent health risks (e.g. unit risk factors). Simplistic comparisons apply typically to irritants (e.g. sulfur dioxide), whereas the estimation of dosages and subsequent health risks would be used to estimate incremental morbidity, mortality, and cancer risks. Health risk criteria relevant to the current study are available from international, peer-reviewed databases. The most widely used databases include the World Health Organisation and the US EPA. This study applies these concepts were required.

Air quality limits and fallout rates for local compliance have been issued nationally by the DEA and SANS.

The effective dose calculation followed the methodology presented in the IAEA Safety Report No. 19 (IAEA, 2001). This report provides the information necessary to allow the legal person responsible to "make an assessment of the nature, magnitude and likelihood of the exposures attributed to the source" (IAEA, 1996). It provides a practical generic methodology for assessing the impact of radionuclide discharges in terms of the resulting individual and collective radiation doses. This methodology allows for the specification and use of site-specific climatic and environmental conditions and is therefore not restricted to specific locations.

1.2.3 Assumptions and Limitations

The following sections summarise the available sources of information and assumptions where necessary. The limitations and significance of the limitations are also discussed.

(a) Baseline Air Concentration Data

(i) Radiation Observations

On-site radiation dose measurements at Koeberg for the period 1984 – 2006 were provided by Eskom for the assessment. The NNR 2009 Annual Report was used to supplement these dose values for the period including 2008. Radiation measurements from Eskom's Environmental Surveillance Programme, which covers a larger area, were also made available for the study. The programme monitors natural radionuclides in terrestrial samples. These observations are useful for comparative purposes against the predicted dose values for the current Koeberg nuclear power station.

Cumulative impacts will be quantified at the Duynefontein Site, thereby taking into consideration the existing radionuclide emissions from the Koeberg NPS.

The impact of the proposed nuclear power station at the other two sites was assessed according to incremental dose, as stipulated by the NNR.

(ii) Criteria Air Pollutants

A number of air quality monitoring stations exist in the City of Cape Town, which could provide an indication of the air quality in the vicinity of the Duynefontein Site. Monitoring data were supplied by the Air Quality Monitoring Section, Scientific Services of the City of Cape Town for the period 2000 to 2007. The monitoring data include sulfur dioxide, oxides of nitrogen, ozone and particulate air concentrations. Although background air concentrations could potentially be extrapolated from observations made at Table View since this is the closest air quality observation point, it is located within a residential and commercial area, and therefore regarded to be significantly higher than the levels currently expected at the Duynefontein site. The closest air pollution sources to Duynefontein include the Open Cycle Gas Turbines at Atlantis (most significantly nitrogen dioxide) and the emergency diesel generators at Koeberg. In the absence of any better information, using the Table View observations could therefore be regarded as conservative for the current conditions. Future developments in the greater Cape Town area (e.g. Atlantis towards the northeast of the Duynefontein site) could however result in increased air pollution levels. The assumption of using the Table View observations may therefore be considered appropriate as an enveloping air quality condition.

Due to the absence of any industrial activities nearby the Thyspunt and Bantamsklip sites, the current air quality is regarded pristine. Any future air pollution observations would therefore be as a result of the proposed project and any other developments that may arise.

A three-month monitoring campaign (March 2009 to May 2009) has been included in the study to determine baseline sulfur dioxide and nitrogen dioxide air concentrations at all three sites.

Deposition rates of sulfur dioxide and airborne chlorides are also monitored as part of the corrosion monitoring programme at the Bantamsklip and Thyspunt Sites. The atmospheric corrosivity at these two sites has been monitored in accordance with ISO Standard 9225 (Measurement of Pollution). Data for the period July 2008 to June 2009 are available.

(b) Meteorological Data and Climatology

Upper air meteorological data are available from the South African Weather Service (SAWS) limited area prediction model (Eta Model)[9]. This data include height above sea level, temperature, wind direction and wind speed for various levels. Eight daily data points for various pressure levels (typically, 800 hPa, 750 hPa, 700 hPa, 650 hPa, 600 hPa, 550 hPa and 500 hPa) can be extracted from the Eta meteorological simulations closest to each of the sites included in the study.

[9] The Eta Model is a state-of-the-art atmospheric model used for research and operational purposes. While the primary use of the model has been for regional weather prediction, the model has been very successful also in regional climate and seasonal prediction applications.

(i) Duynefontein

Eskom operates five automatic weather stations at Duynefontein. The station locations are all located within 23 km of the Koeberg. At the Koeberg there are two towers of 120 m and 50 m in height, respectively, with instruments on the 10 m, 50 m, 85 m and 120 m level. The 50 m tower is a back-up of the main 120 m tower.

Horizontal wind speed components are measured at 10 m and 85 m, whereas both horizontal and vertical winds are measured at 50 m and 120 m heights. Temperature is measured at 10 m, 50 m and 120 m.

The meteorological system at the Duynefontein site began operations in 1979. It has continued to function continuously despite a meteorological tower being destroyed in a windstorm in May 1987. Monthly printed reports are forwarded to the NNR in accordance with the nuclear licence requirements.

The closest SAWS meteorological station to the Duynefontein site is located at Cape Town International Airport. Meteorological data are recorded on a 24-hour basis. The SAWS database and their summary reports are available for long-term analyses (see Appendix F).

(ii) Bantamsklip

Historical meteorological data are limited for the Bantamsklip site. Eskom conducted a three-year meteorological data collection campaign for the period 1987 to 1989 at three locations nearby the Bantamsklip site, namely Die Gruis, Buffeljagsbaai and Danger Point.

A 10 m mast, fully equipped with meteorological instrumentation to measure the wind vector, air temperature, relative humidity, barometric pressure and rainfall was erected at the site on 9 January 2008. A longer period of data is available from the SAWS automatic weather station at Hermanus, where recordings started in 2001. These measurements are made at a reference height of 10 m above ground level. Hourly averages for wind speed, wind direction, dry bulb temperature, relative humidity, barometric pressure and rainfall were included.

A comparison of available local meteorological data at Bantamsklip with the long-term SAWS observations at Hermanus will provide an estimate of uncertainty in predictions using the latter data.

Eskom also provided a number of reports on meteorological observations for the period 1987 to 1989 at Bantamsklip. These are listed in Appendix F.

(iii) Thyspunt

As for Bantamsklip, historical meteorological data are limited. Eskom collected meteorological data at four sites in the vicinity of Thyspunt, namely De Hoek, Thyspunt, Klippepunt, and Brakkeduine between December 1986 and September 1988. Data collection continued again at Thyspunt until November 1989.

A 10 m mast, fully equipped with meteorological instrumentation to measure the wind vector, air temperature, relative humidity, barometric pressure and rainfall has recently (10 January 2008) been erected at the site.

Long-term meteorological data have been collected by the South African Weather Services using their automatic weather station at Cape St. Francis. Wind speed and direction measurements are made at approximately 10 m above ground level, similar to the on-site monitoring station. Since the Thyspunt site and Cape St. Francis are relatively close to each other (approximately 15 km separation distance), with no mountain ranges between the sites and exposed to the same coastline weather conditions, the dispersion conditions are expected to be similar. A comparative analysis of the on- and off-site (SAWS) observations would allow an evaluation of the representativeness of the off-site data for the purposes of this study.

Eskom provided a number of reports on meteorological observations for the period 1987 to 1988 at Thyspunt. These are listed in Appendix F.

(c) Emission Rates and Estimation Methods

(i) Radionuclide Emissions

The Koeberg and proposed PBMR DPP emissions were provided by Eskom and PBMR for the impact assessment. The assumption was made that these emissions were accurate and correct.

Radio-nuclide emissions for the preferred alternative reactor designs were obtained from the respective vendors via Eskom. For generic model purposes the maximum annual dose is assumed to be the dose that would be received in a discharge period of 30 years. In the absence of any better knowledge, the emission rates were kept constant for this 30-year period.

(ii) Non-Radionuclide Emissions

Since details on the construction of the plant were not available, this impact could not be completed in detail. Assumptions made for construction activities consisted of:

- Exposed areas were confined to the plant footprints provided by Eskom;
- Excavation activities ceasing before actual construction of the buildings activities take place;
- The silt loading on paved road surfaces varied between 4.3 and 8.2 g/m² based on typical averages; and
- Single particle size distributions of dune sand averaged over a depth of 2 to 3 m, applied for the entire depth of excavations.

Emissions and stack design specifications for the auxiliary power generators were based on the Siemens SGT 700 Gas Turbine design using diesel fuel.

(d) Short-Range Atmospheric Dispersion Simulations

(i) Atmospheric Dispersion Model Selection

In assessing the significance of sources both the extent of emissions (see Section 1.2. (b) and Appendix B, Section 8.2.2) and the magnitude of impacts on ambient air quality needs to be taken into account. The impact of a source is a function of the prevailing meteorology, the extent, height and duration of emissions and the proximity of the source to sensitive receptors. Dispersion models facilitate the prediction of the behaviour of air pollutants once released in the air. It computes the dilution of the pollutants and their travel direction and distance. The model results are expressed as concentrations (normally at ground level) and deposition rates over different periods of exposure.

Dispersion models compute ambient concentrations as a function of source configurations, emission strengths and meteorological characteristics, thus providing a useful tool to ascertain the spatial and temporal patterns in 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 required purpose.

The IAEA recognises Gaussian-plume models (IAEA, 1980) to be well suited for use in radiological assessment activities and specifically near-field (typically less than 50 km) applications where the steady-state meteorology[10] assumption is most likely to apply. The Gaussian model is considered appropriate for representing the dispersion of either continuous or long term intermittent releases. For the purposes of this report long term intermittent pollutant releases from nuclear power station vents and fugitive dust sources (during construction) are defined as those for which the short term source strength, released momentarily or continuously per day, does not exceed 1% of the maximum annual source strength, estimated assuming a constant release rate (Heinemann and Vogt, 1980).

As discussed in Section 1.1.2, the NNR provided guidance[11] on acceptable atmospheric dispersion models, and essentially adopted the US EPA's dispersion models used for regulatory purposes. They include the following models:

- Industrial Source Complex Model (ISC model);
- Fugitive Dust Model (FDM);
- Complex Terrain Dispersion Model (CTDM);
- Rough Terrain Dispersion Model (RTDM); and
- INPUFF.

These are briefly discussed below.

ISC is generally regarded as the workhorse of dispersion models. It is a steady-state Gaussian plume model which can be used to assess pollutant concentrations from a wide variety of sources associated with an industrial complex. This model can account for the following: settling and dry deposition of particles; downwash; point, area, line, and volume sources; plume rise as a function of downwind distance; separation of point sources; and limited terrain adjustment. ISC operates in both long-term and short-term modes. It should, however, be noted that the US EPA has subsequently replaced this model by a new generation dispersion mode, i.e. the AERMOD model. The AERMOD model is discussed further below.

The US-EPA's Fugitive Dust Model (FDM) is an air quality model specifically designed for computing concentration and deposition impacts from fugitive dust sources. The model is based on the Gaussian Plume formulation for computing concentrations, but has adaptations for improved gradient-transfer deposition algorithm. FDM can accommodate point, line and area sources.

[10] In these models, the wind field and atmospheric dispersion are assumed to be uniform in time (i.e. constant over a model time step of 1 hour) and the modelling area

[11] Guideline on the Assessment of Radiation Hazards to Members of the Public from Mining and Mineral Processing Facilities (LG-1032)

The Complex Terrain Dispersion Model (CTDM) was the result of the Complex Terrain Model Development Project initiated by the US EPA to develop a practical, refined plume model for elevated point sources near complex terrain. CTDM was developed to primarily model nighttime, stable conditions associated with maximum short-term impacts. Additional algorithms for estimating impacts during stable conditions have been integrated with CTDM to form CTDM Plus Algorithms for Unstable Situations (CTDMPLUS). CTDMPLUS is a Gaussian plume dispersion model for point sources on or near isolated terrain features. CTDMPLUS does not simulate calm meteorological conditions and under these conditions, no concentrations are estimated or assumptions are made with regards to plume height variables. (US EPA, 1989)

The Rough Terrain Diffusion Model (RTDM3.2) is a Gaussian plume model intended to estimate ground-level concentrations in rough (or flat) terrain in the vicinity of one or more co-located point sources. RTDM is a screening model that is usually applied before the refined air quality model to determine if refined modelling is needed.

INPUFF is a Gaussian INtegrated PUFF model that uses the Gaussian puff[12] diffusion equation to compute the contribution to the concentration at each receptor from each puff every time step. Computations in INPUFF can be made for a single point source at up to 25 receptor locations. INPUFF computer code includes stack downwash, wind speed extrapolated to release height, temporally variable source characteristics, temporally and spatially variable wind field (user defined), terrain effects through the user supplied wind field and the consideration of a moving source. (US EPA, 1984)

Other newer and more advanced models have also become more assessable and acceptable for use subsequent to the publication of this guideline. For example, the US EPA's CALMET/CALPUFF suite of models, which can accommodate complex terrain, land-sea interfaces and meso-scale (large terrain, > 50 km) simulations. Similar to the INPUFF model, this model is also based on Gaussian puff diffusion theory.

There are a number of other well-known dispersion models used in the nuclear applications including PCCOSYMA and PAVAN. However, these models do not include methods to simulate complex terrain, and should only be used under conditions of limited topographical complexity. The topography near the Bantamsklip and Thyspunt sites is relatively complex and it is therefore recommended to use dispersion models that can accommodate complex terrain. Although the topography at Duynefontein is only significant after about 10 km, the same model should be used as for the other two sites for comparative purposes. It is therefore recommended to employ more recent (new generation) models for the purpose of simulating the dispersion process, as described next.

The US EPA ISC model has been replaced by AERMET/AERMOD model suite as the preferred US regulatory dispersion model. The AERMOD model, albeit still based on the Gaussian plume, has been improved with respect to its treatment of atmospheric dispersion classifications and topography. The model's concentration estimates are based on a steady-state plume approach with significant improvements over commonly applied regulatory dispersion models. Complex terrain influences are provided by combining a horizontal plume state and a terrain-following state. Dispersion algorithms are specified for convective and stable conditions, urban and

[12] The plume is represented by sequentially released puffs, with release intervals such that the super-positioning of the puffs closely simulate the continuous plume.

rural areas, and in the influence of buildings and other structures. In convective conditions (typically experienced during calm, hot summer periods), the effects of random vertical updraft and downdraft velocities are simulated with a bi-Gaussian probability density function. In both convective and stable conditions, the mean vertical wind speed is assumed equal to zero.

An alternative to the AERMOD model would be the UK's Atmospheric Dispersion Modelling System (ADMS) dispersion model. The ADMS model was developed by the Cambridge Environmental Research Consultants (CERC), and similar to AERMOD, the ADMS 4 is a new generation air dispersion model which means that it differs in a number of aspects from the regulatory models traditionally used. The most important differences are (i) the description of atmospheric stability as a continuum rather than as discrete classes (the atmospheric boundary layer properties are described by two parameters; the boundary layer depth and the Monin-Obukhov length, rather than in terms of the single parameter Pasquill Class) and (ii) in allowing more realistic asymmetric vertical plume behaviour under unstable atmospheric conditions. Dispersion under convective meteorological conditions uses a skewed Gaussian concentration distribution (shown by validation studies to be a better representation than a symmetric Gaussian expression).

ADMS4 is currently used in many countries worldwide and users of the model include Environmental Agencies in the UK and Wales, the Scottish Environmental Protection Agency (SEPA) and regulatory authorities including the UK Health and Safety Executive (HSE). It has also been the subject of a number of inter-model comparisons (CERC 2000); one conclusion of which is that it tends to provide conservative values under unstable atmospheric conditions in that, in comparison to the older regulatory models, it predicts higher concentrations close to the source.

The AERMOD dispersion model is currently not able to incorporate the potential development of the thermal internal boundary layer (TIBL) at the coast. ADMS on the other hand is able to model these effects, but cannot take topographical influences into account simultaneously when making this calculation.

This assessment adopted the use of AERMOD. The difference between the predictions of AERMOD and ADMS 4 is given in Appendix C.

(ii) Uncertainty

There will always be some error in any geophysical model, but it is desirable to structure the model in such a way to minimise the total error. A model represents the most likely outcome of an ensemble of experimental results. The total uncertainty can be thought of as the sum of three components: the uncertainty due to errors in the model physics; the uncertainty due to data errors; and the uncertainty due to stochastic processes (turbulence) in the atmosphere.

The stochastic uncertainty includes all errors or uncertainties in data such as source variability, observed concentrations, and meteorological data. Even if the field instrument accuracy is excellent, there can still be large uncertainties due to unrepresentative placement of the instrument (or taking of a sample for analysis). Model evaluation studies suggest that the data input error term is often a major contributor to total uncertainty. Even in the best tracer studies, the source emissions are known only with an accuracy of ±5%, which translates directly into a minimum error of that magnitude in the model predictions. It is also well known that wind direction errors are the major cause of poor agreement, especially for relatively short-term predictions (minutes to hourly) and long downwind distances. All of the above factors contribute to the inaccuracies not even associated with the mathematical models themselves.

Although the AERMOD model has been shown to be an improvement on the ISC model, especially short-term predictions, the range of uncertainty of the model predictions is -50% to 200%. This apparently large uncertainty needs to be seen in context: air concentrations span over a logarithmical scale. Inaccurate predictions at low concentrations can result in large uncertainties. So, for instance, comparing a prediction of 2 µg/m³[13] to an observation of 1 µg/m³ is equivalent to an over-prediction of 200%. However, using the absolute error of 1 µg/m³ at a higher concentration e.g. 101 µg/m³ compared to observation of say 100 µg/m³, is only small over-prediction. The accuracy improves with fairly strong wind speeds and during neutral atmospheric conditions.

(e) Long-Range Atmospheric Dispersion Simulations

The accuracy of a steady state Gaussian air dispersion model decreases with distance from the source of the release. For that reason, for example, the US EPA does not approve the use of a straight line steady state Gaussian plume model to predict the dispersion of a pollutant beyond 50 km. As a steady state Gaussian plume model, AERMOD assumes that meteorological conditions are constant and uniform across the study area (apart from special treatments in the vicinity of topographical features) for each time period of simulation. As alternatives, the meso-scale models such as the US EPA's CALPUFF/CALMET modelling suite, the Danish RIMPUFF, NOAA's HYSPLIT, and many others could be employed.

For the reasons given above, and in order to simulate long-range dispersion from the nuclear power station, the HYSPLIT model was selected for use in this study. The HYSPLIT_4 (HYbrid Single-Particle Lagrangian Integrated Trajectory) model was selected since it is a complete system for computing trajectories, complex dispersion and deposition simulations using either puff or particle approaches. The dispersion of a pollutant is calculated by assuming either a Gaussian or Top-Hat horizontal distribution within a puff or from the dispersal of a fixed number of particles. Air concentration calculations require the definition of the pollutant's emissions and physical characteristics (if deposition is required).

The routine meteorological data fields required for the calculations may be obtained from existing archives or from forecast model outputs already formatted for input to HYSPLIT. In addition, several different pre-processor programmes are provided to convert NOAA (National Oceanographic and Atmospheric Administration), NCAR (National Centre for Atmospheric Research) re-analysis, or ECMWF (European Centre for Medium-range Weather Forecasts) model output fields to a format compatible for direct input to the model.

(f) Health Risk and Nuisance Guidelines

The ambient air quality guidelines and standards for pollutants relevant to the current study are available from international, peer-reviewed databases. The most widely used include the World Health Organisation and the US EPA.

[13] Air concentrations are typically expressed as mass (e.g. micrograms, or µg) per volume (e.g. cubic metre, or m³).

As discussed under the methodology section, non-radioactive air releases will be assessed according to the air quality limits and fallout rates issued by DEA and SANS.

For licensing of the proposed nuclear power station, it must be demonstrated that the Basic Licensing Requirements (BLR) formulated in the Regulations on Safety Standards and Regulatory Practices published as Regulation No. R388 dated 28 April 2006 (RSRP) are met. National Nuclear Regulator Act, 1999 (Act No. 47 of 1999) Radiation dose criteria are published in the Regulation for dose to plant personnel and to members of the public.

The inhalation rate used to calculate radiation dose was based on the inhalation of an adult male provided by the International Commission on Radiological Protection Publication 71 (ICRP 71). The assessment only considered inhalation exposure. This dose should be added to the other exposure pathways (e.g. ingestion).

2 DESCRIPTION OF AFFECTED ENVIRONMENT

The aspects regarded as important to describe the air quality impact and climate of the three sites include the location, the topographical features, the meteorology (micro- to synoptic scale), existing levels of air pollution, the land use and the sensitive receptors. Each of the above-mentioned aspects is described in more detail in the sections below.

2.1 Site Locations

The three potential sites that were included in the study, viz. Duynefontein and Bantamsklip in the Western Cape and Thyspunt in the Eastern Cape are shown in Figure 2-1.

Figure 2-1: Location of three potential Nuclear-1 Power Station sites

2.1.1 Duynefontein

Whilst Thyspunt and Bantamsklip are situated in relatively pristine areas, the Duynefontein site already includes the country's only nuclear power station, i.e. the Koeberg Nuclear Power Station. Koeberg (owned and operated by Eskom) was constructed in 1976, with Unit 1 being synchronised to the grid on 4 April 1984. Unit 2 followed shortly thereafter on 25 July 1985. The proposed location for the Nuclear-1 Power Station would be towards the north of Koeberg, as shown in Figure 2-2.

2.1.2 Bantamsklip

The proposed location for Nuclear-1 at Bantamsklip site is shown in Figure 2-3.

2.1.3 Thyspunt

The proposed location for the nuclear power station at Thyspunt site is shown in Figure 2-4.

2.2 Land Use and Topography

Given that the project will be associated with low level non-nuclear emissions (e.g. from construction operations) and elevated emissions (stacks), the project has the potential of impacting on receptors in the near (up to 5 km) and medium fields (up to 20 km). When assessing the impact of emissions from the proposed power station, it is important to identify the land use in the surrounding area. This is especially important for estimating the impact from radionuclide emissions. This section is not intended to be a comprehensive account of the land use, but merely to provide an initial indication of the activities in the near vicinity of the proposed sites.

2.2.1 Duynefontein

The land use in the immediate vicinity of the Duynefontein site is characterised by industrial activity in the form of Koeberg (Figure 2-5). No industrial air pollution sources other than Koeberg exist in the immediate Duynefontein area. Industrial processes are present at Atlantis (Open Cycle Gas Turbine Power Station, brickworks and other smaller commercial activities) about nine km northeast, landfill operations at Vissershok (5 km southeast) and a Petroleum refinery (21 km south-southeast of the Duynefontein site. Vehicles along the main roadways (e.g. R27) and nearby residential areas also contribute to the airshed, especially oxides of nitrogen.

Large tracts of cultivated land extend ~5 km to the east of the site. The closest river to the site is the Diep River ~25 km to the south.

Residential areas in the vicinity of the proposed operations include Duynefontein (2 km south) and Melkbosstrand (~5 km southeast). Larger residential developments within a 15 km radius are Atlantis and Milnerton (Figure 2-6). It is clear that the immediate area has a population density of less than 500 people per km^2 (Census data 2007, Statistics South Africa).

Although within the immediate vicinity of the site the topography is relatively undulating, the topography further away rises towards the north east (Atlantis, 200 m) with the Dassenberg to the north of the site and east (Olifantskop, 360 m) to southeast (Kanonberg, 430 m) (Figure 2-7).

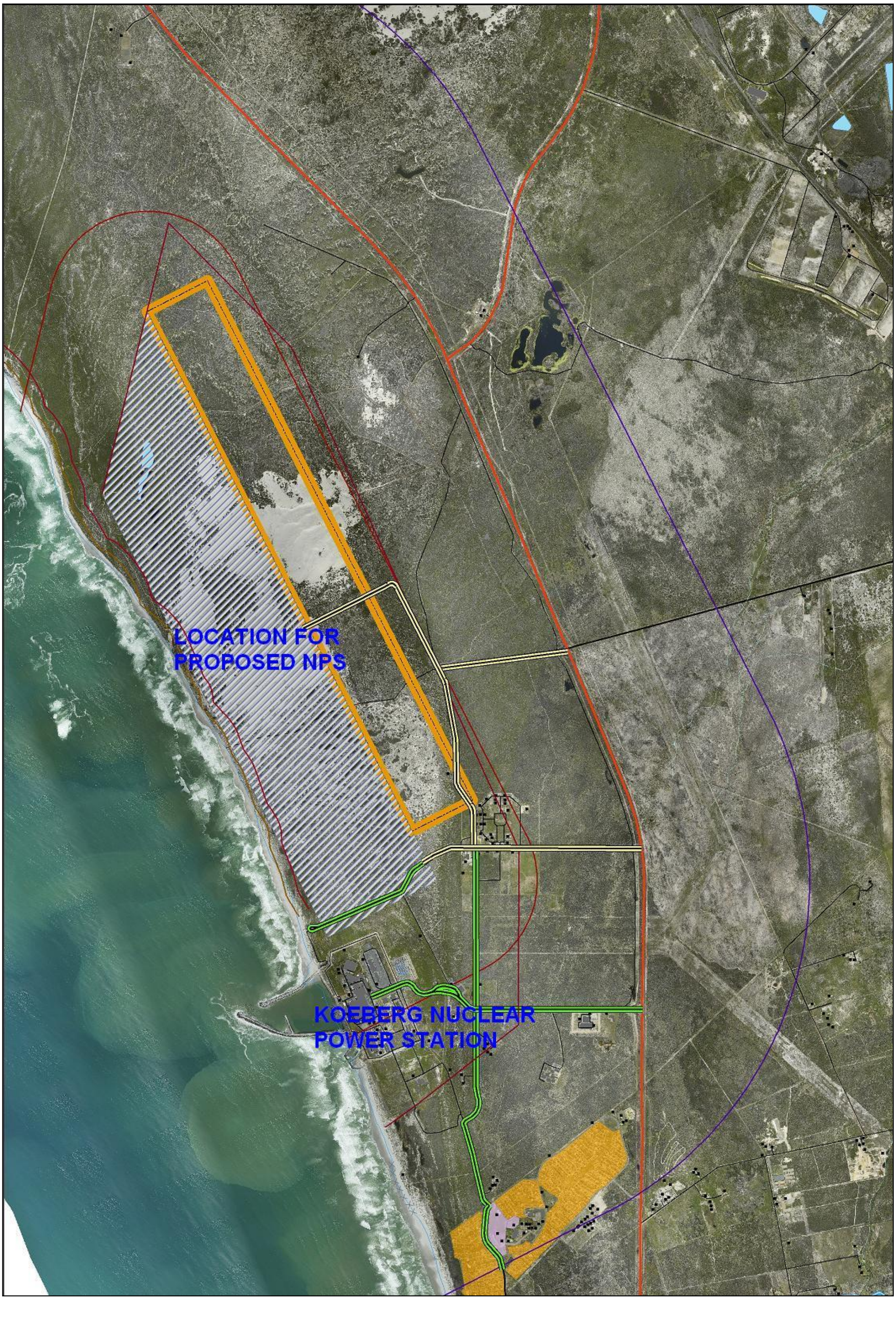


Figure 2-2: Proposed location of Nuclear-1 at the Duynefontein site

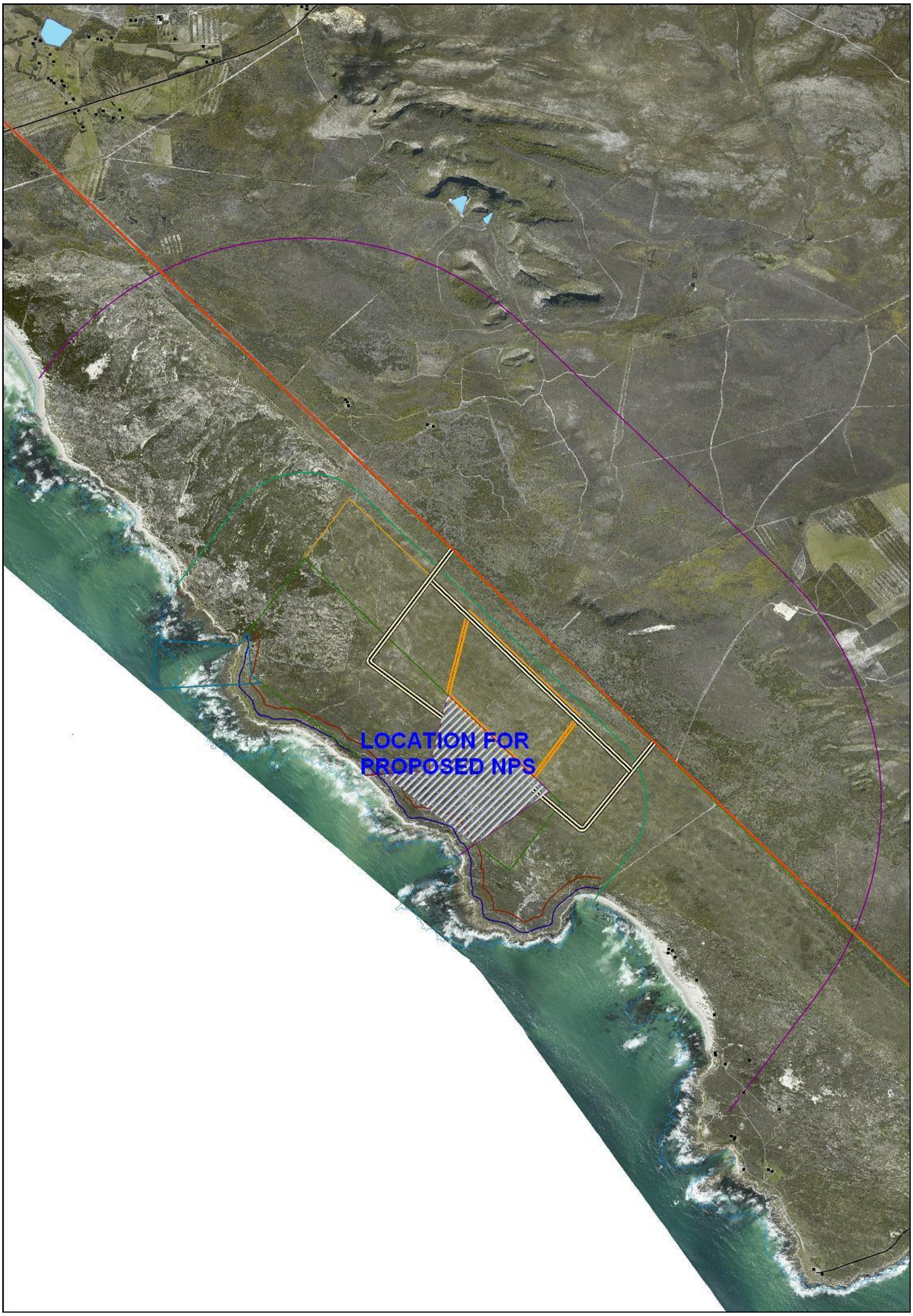


Figure 2-3: Proposed location of Nuclear-1 at the Bantamsklip site

Figure 2-4: Proposed location of Nuclear-1 at the Thyspunt site

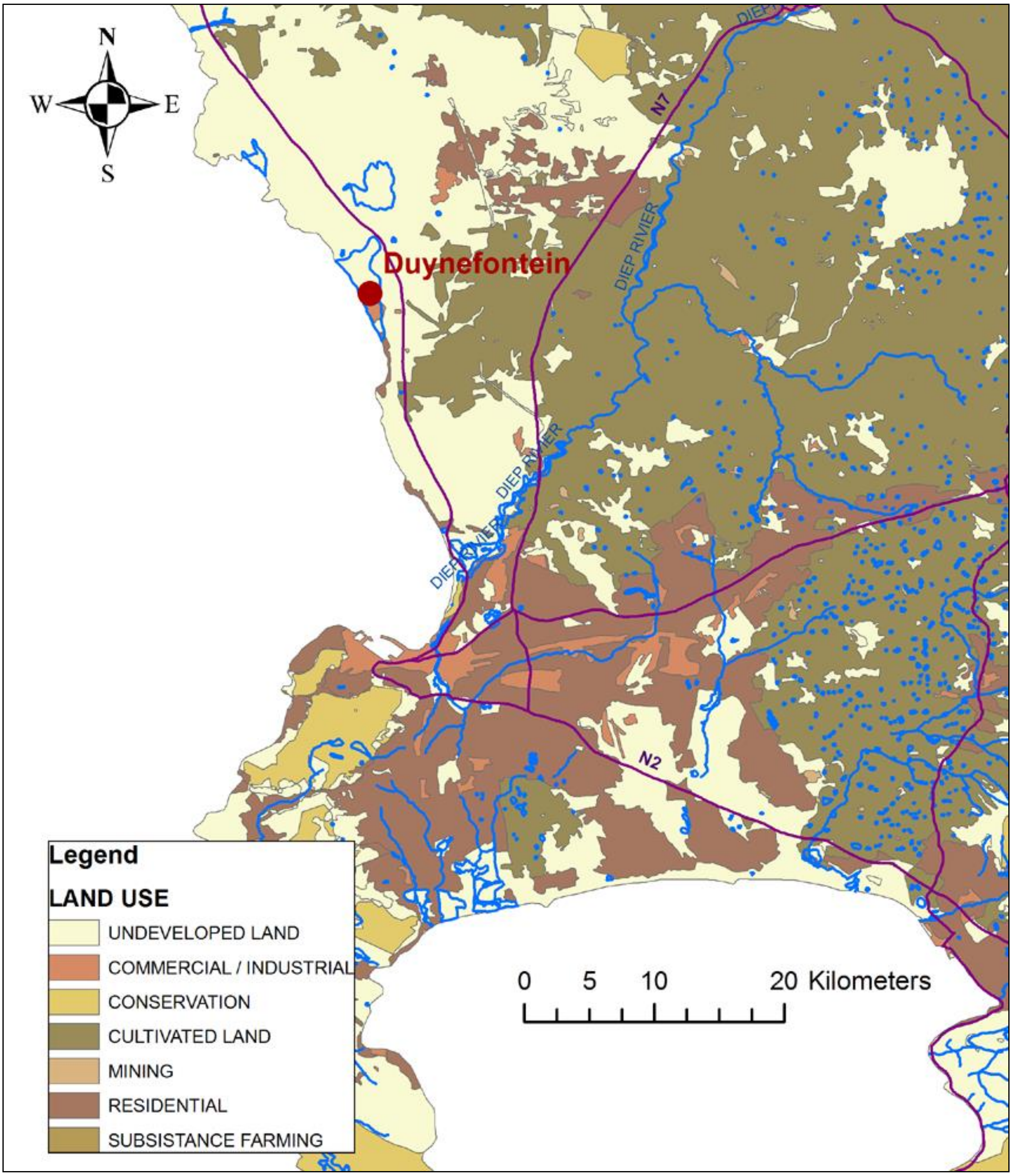


Figure 2-5: Land use in the vicinity of the Duynefontein site

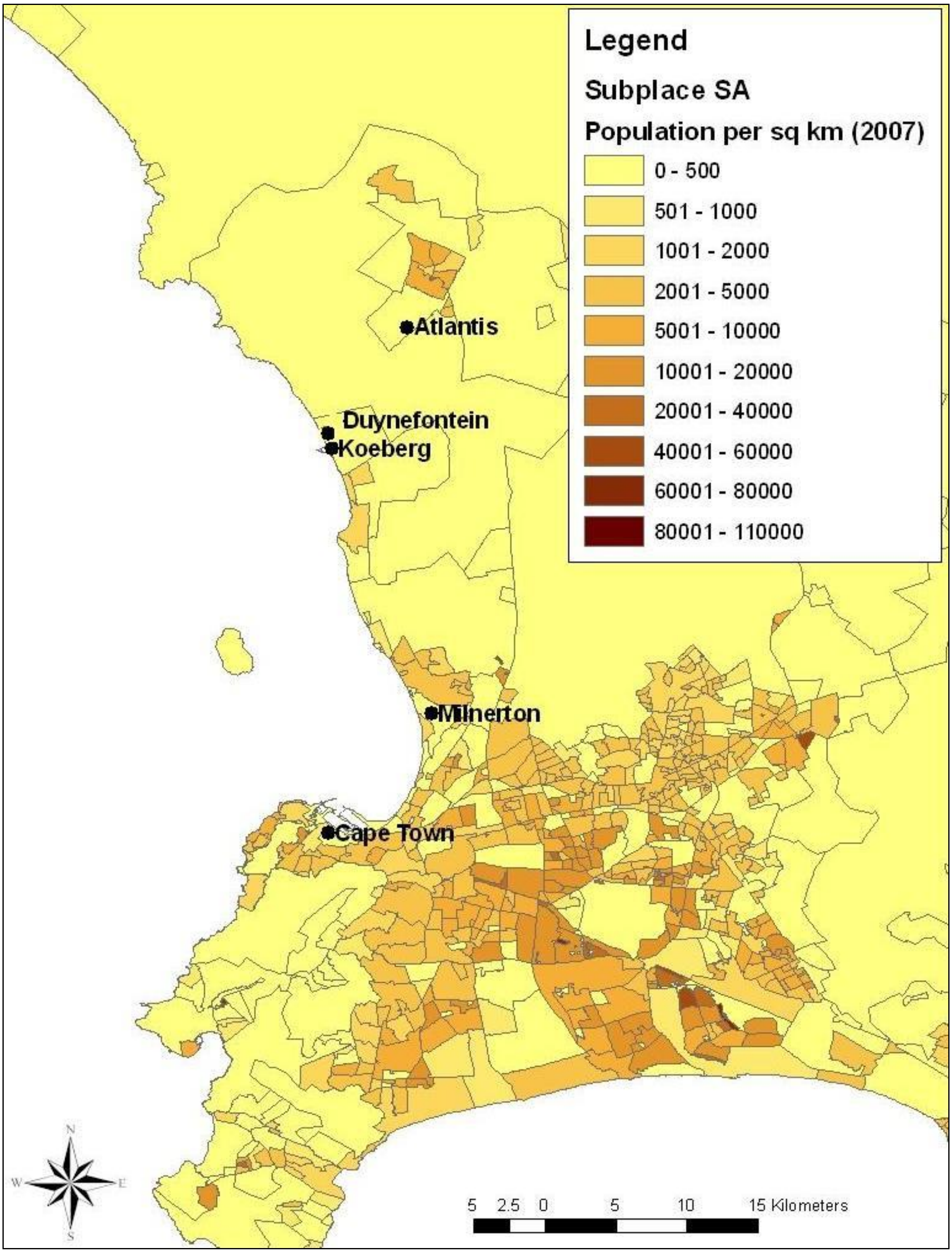


Figure 2-6: Population density in the vicinity of the Duynefontein site (Statistics South Africa 2007)

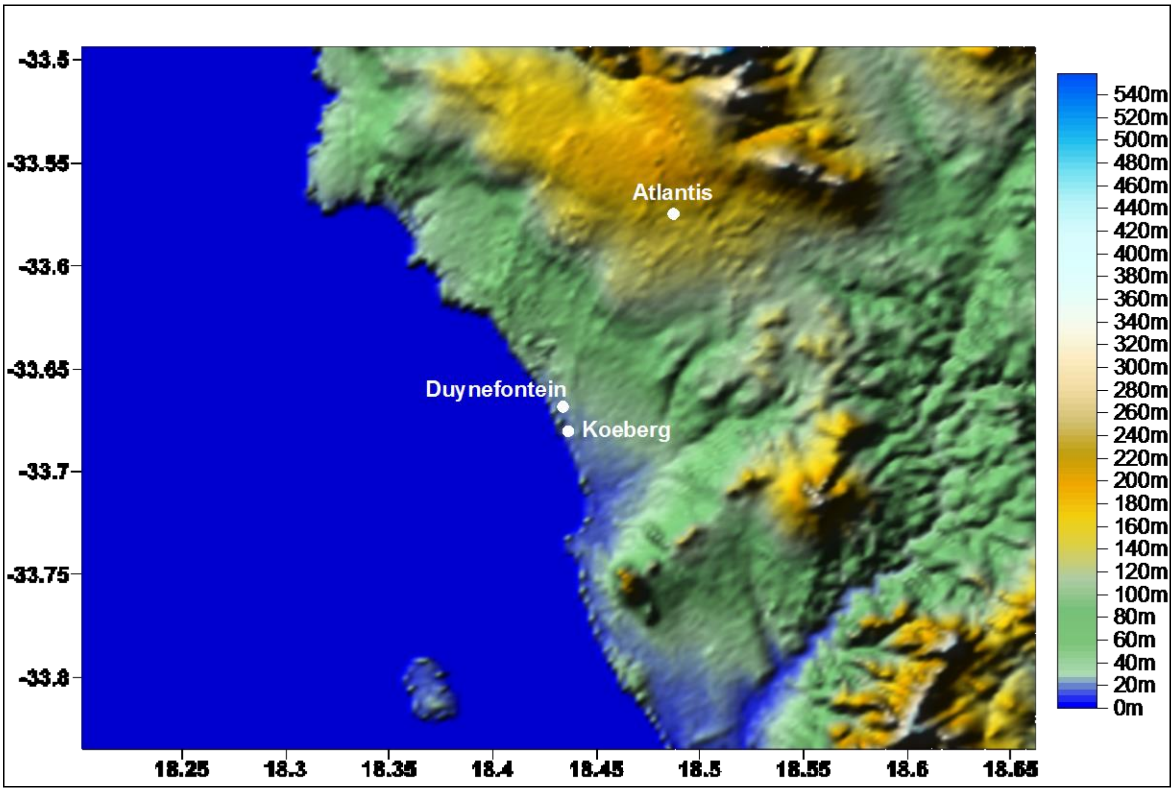


Figure 2-7: Shaded relief profile of the Duynefontein study area

2.2.2 Bantamsklip

Due to the absence of any industrial activities in the vicinity of the Bantamsklip site, current air pollution levels are very low. The closest source of potentially significant air pollution is Hermanus, approximately 44 km northwest of the site.

Conservation land use extends ~7 km to the north and northwest of Bantamsklip (Figure 2-8). The main rivers in the area are the Hagelkraal River (~5 km north of the site) and Kok River (~8 km northeast of the site).

The area is generally characterised by sparse population, with most of the region falling within a population density of less than 500 people per km^2 (Figure 2-9) (Census data 2007, Statistics South Africa). Larger residential areas in the greater region of the proposed operations include Gansbaai (~25 km northwest), Hermanus (~44 km northwest), Struisbaai (east-northeast 47 km) and Bredasdorp (~60 km east northeast). Smaller residential developments closer to the proposed site include Pearly Beach (~10 km northwest) and Die Dam (~10 km southeast).

The region is relatively undeveloped, with most of the agricultural activities towards Pearly Beach and Gansbaai.

The topography near the coastline is relatively flat, becoming undulating further inland with Buffeljagsberg (298 m) to the east and the Koude Mountains (450 m) to the north. To the east of Gansbaai, the topography becomes more mountainous with the Duinefonteinberg (318 m) directly east of the Gansbaai residential area (Figure 2-10).

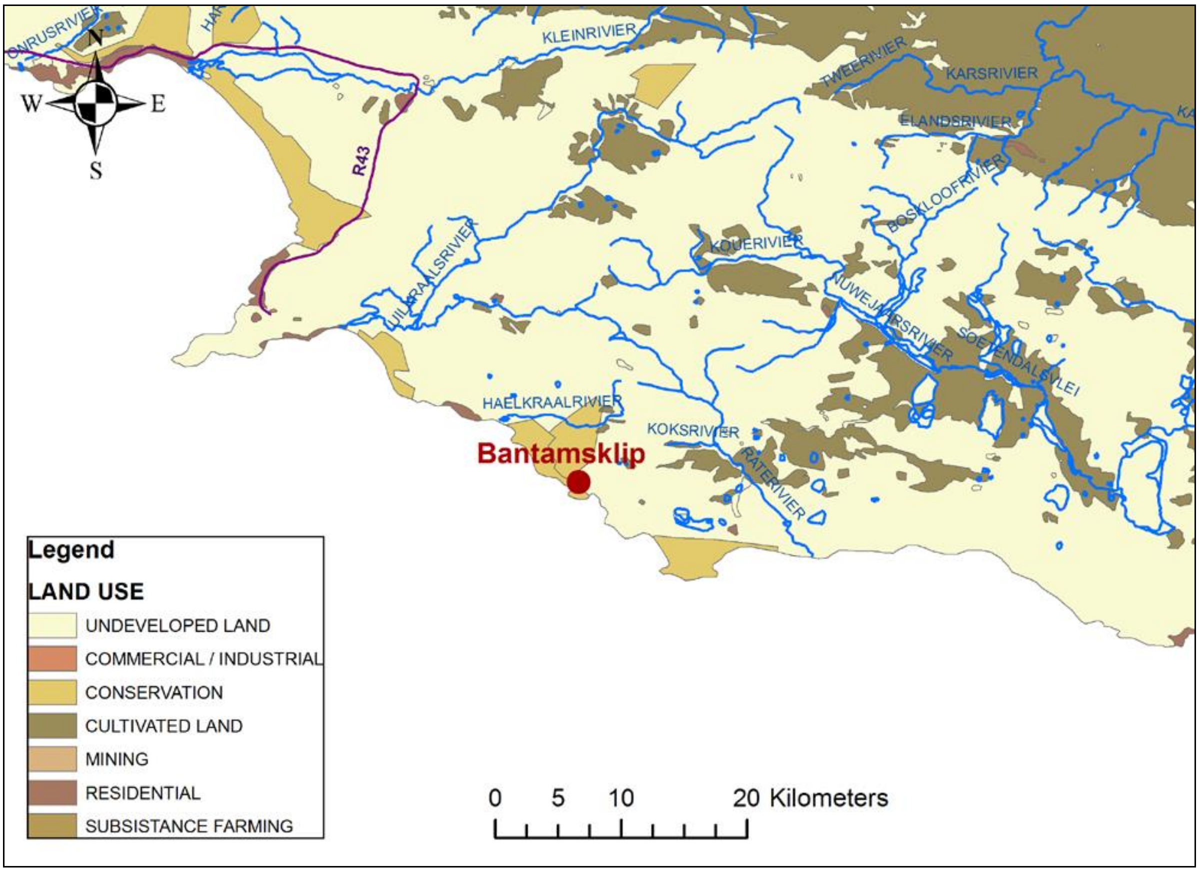


Figure 2-8: Land use in the vicinity of the Bantamsklip site

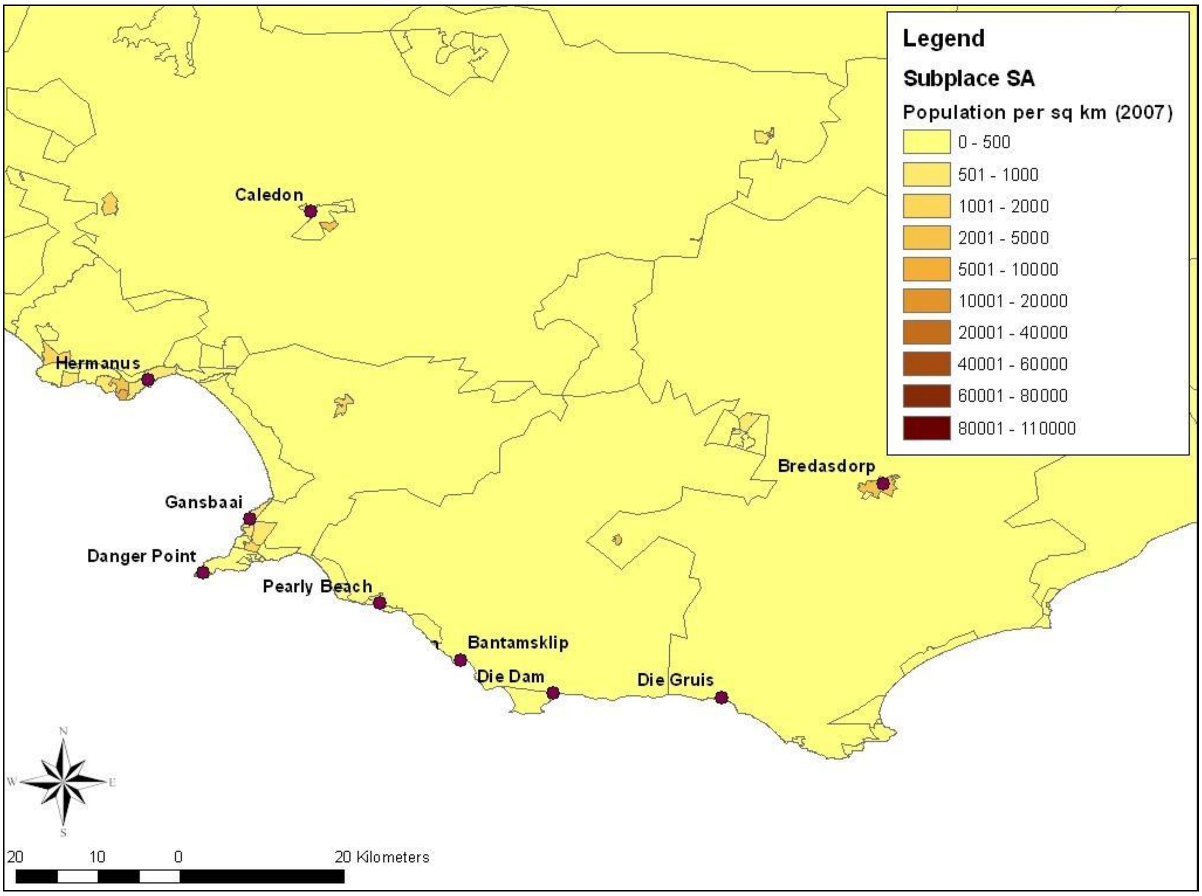


Figure 2-9: Population density in the vicinity of the Bantamsklip site (Statistics South Africa 2007)

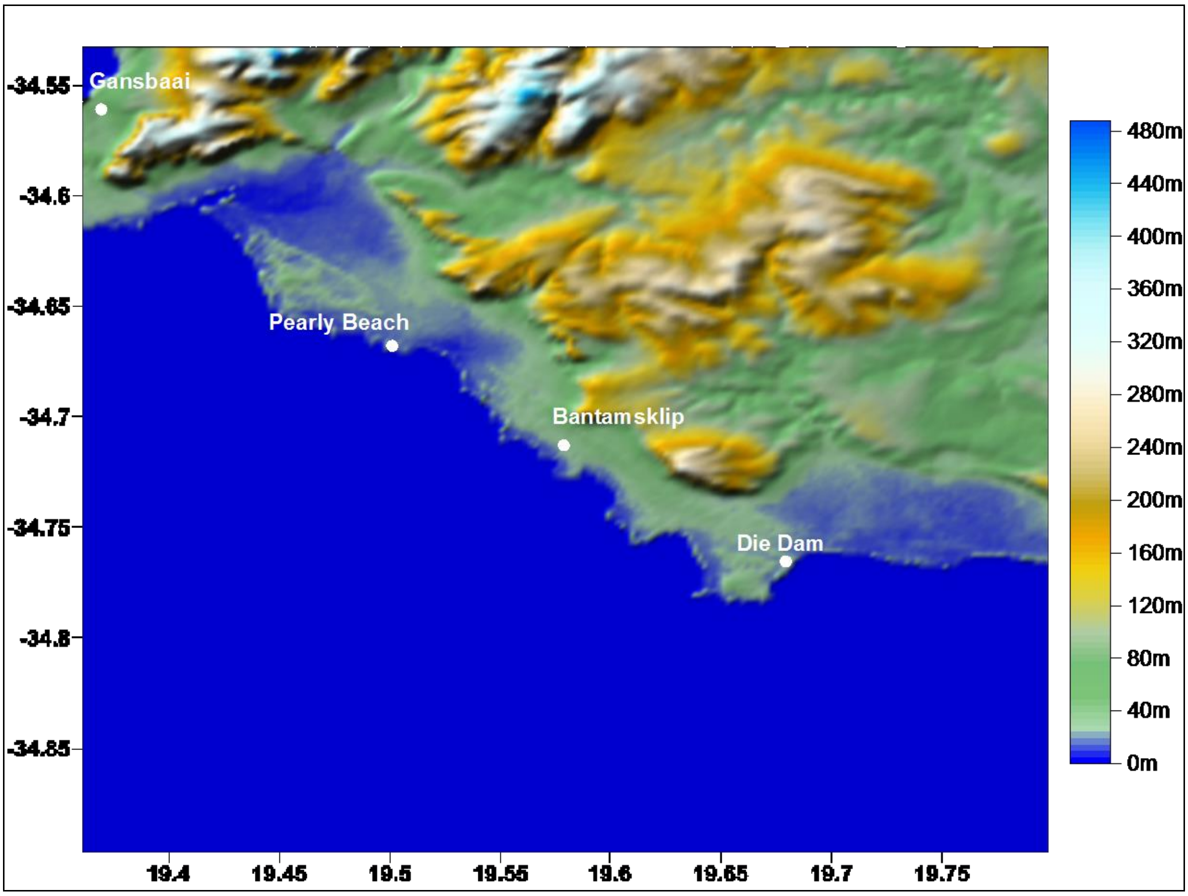


Figure 2-10: Shaded relief profile of the Bantamsklip study area

2.2.3 Thyspunt

At Thyspunt, the land use in the local study area (typically less than 10 km) includes a large portion of vacant land. From approximately 2.5 km north of the site, the land use type consists of large tracts of cultivated land (Figure 2-11). Farming activities mainly include fodder for dairy cows, sheep (predominantly beyond 10 km, northwest of the site) and cattle (meat). Limited game farming occurs towards the north of the site, with wheat fields present to the west and north of the site.

The N2, which extends in an east-west direction, is ~20 km north of the site with the Klipdrif River and the Krom River ~7 km to the west and north of the site, respectively.

The absence of any industrial activities in the vicinity of Thyspunt results in very low current air pollution levels. Cape St. Francis is located 13 km east of the site, and Humansdorp, which is relatively more industrialised, is located approximately 18 km north of the site. However, the prevailing winds, i.e. easterly and westerly, offer little opportunity to carry air pollution from Humansdorp to the site.

Larger residential areas in the vicinity of the proposed operations include Humansdorp (~18km north northeast), Jeffreys Bay (~25 km northeast), St. Francis Links (~10 km east), Sea Vista (~12 km east) and Cape St. Francis (~13 km, east-southeast), (Figure 2-12). Smaller residential developments closer to the proposed site include Oyster Bay (~3 km west), Amaninzi (10km northeast) and Klippepunt (~10 km west).

The population density is predominantly less than 500 people per square kilometre (Figure 2-12). Increased densities are shown for Humansdorp and Jeffreys Bay (2000 to 5000 per km^2) (Census data 2007, Statistics South Africa).

Resistant rock structures in the vicinity of the Thyspunt site are visible in the increase in relief extending from the northwest to the southeast between layers of lower relief (Figure 2-13).

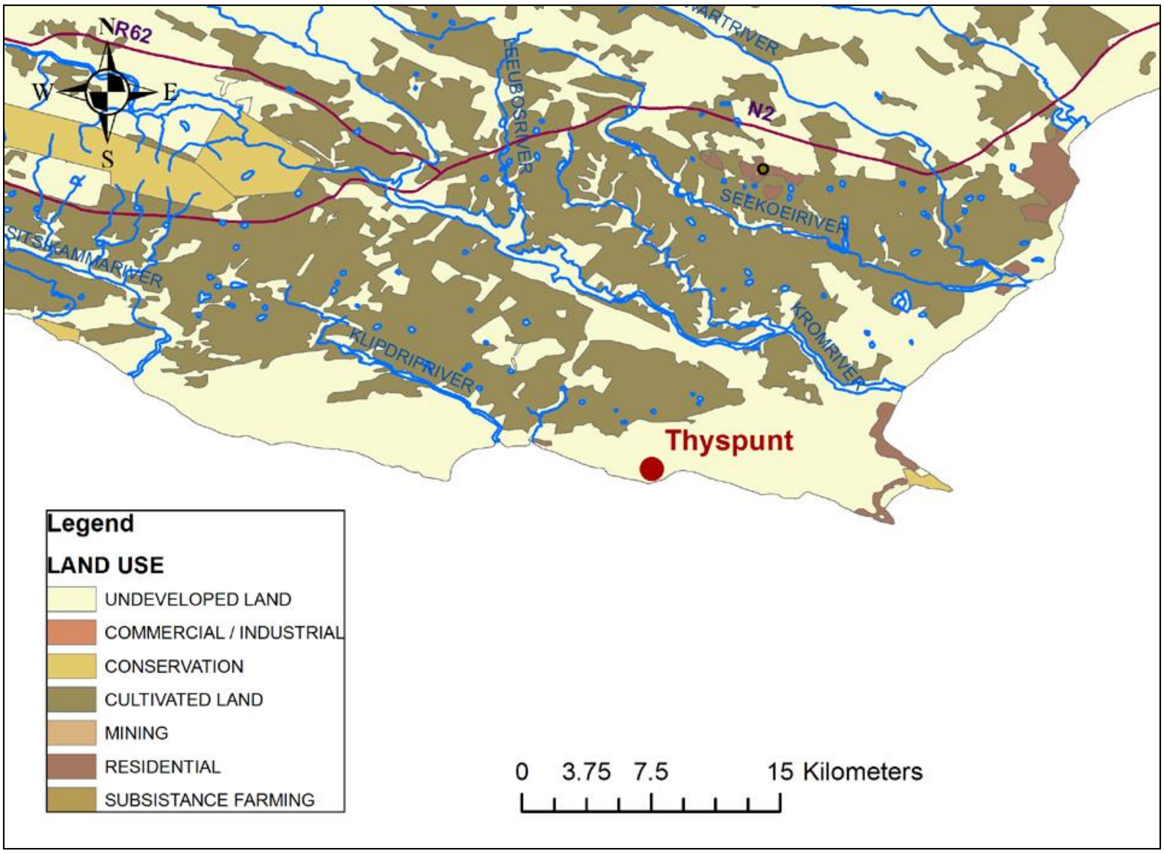


Figure 2-11: Land use in the vicinity of the Thyspunt site

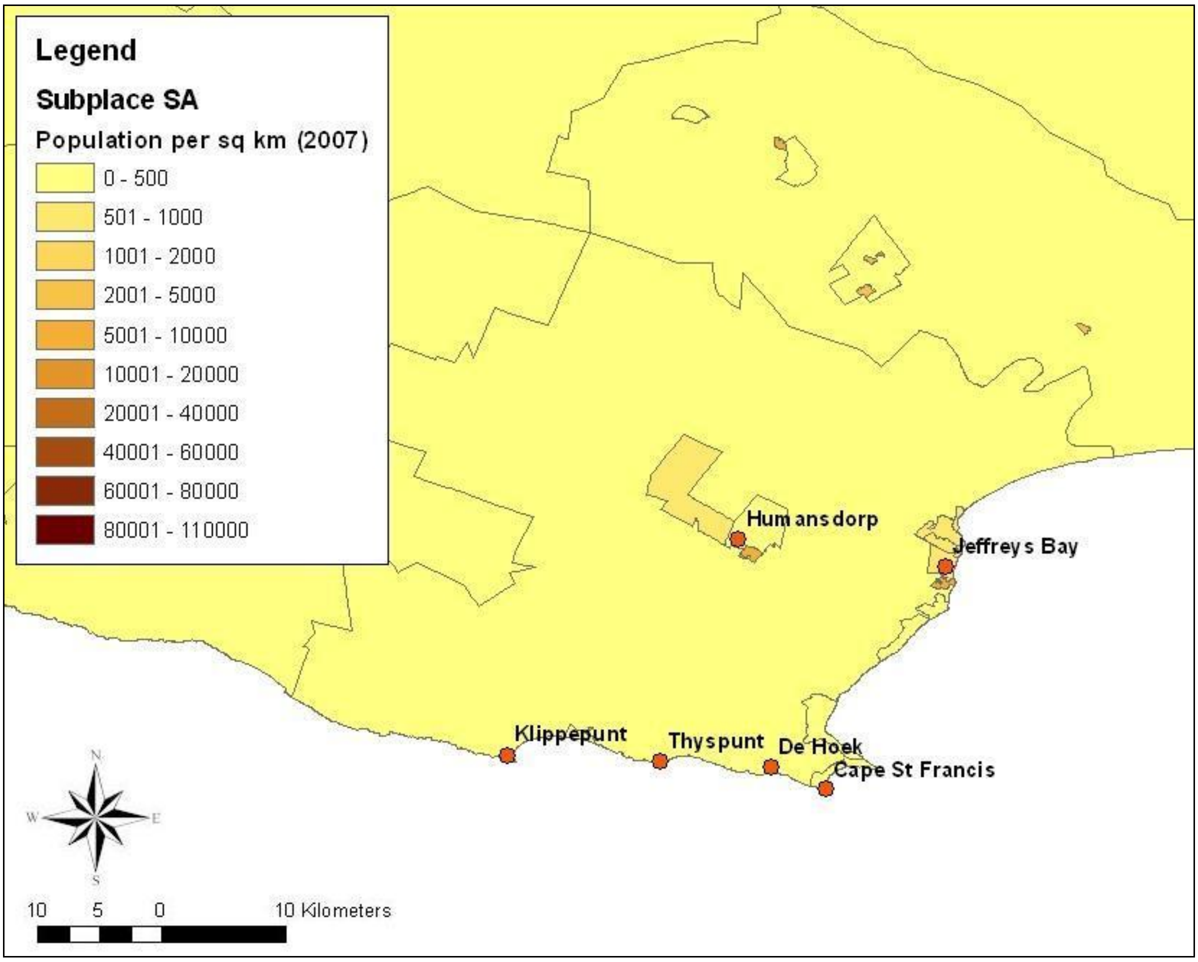


Figure 2-12: Population density in the vicinity of the Thyspunt site (Statistics South Africa 2007).

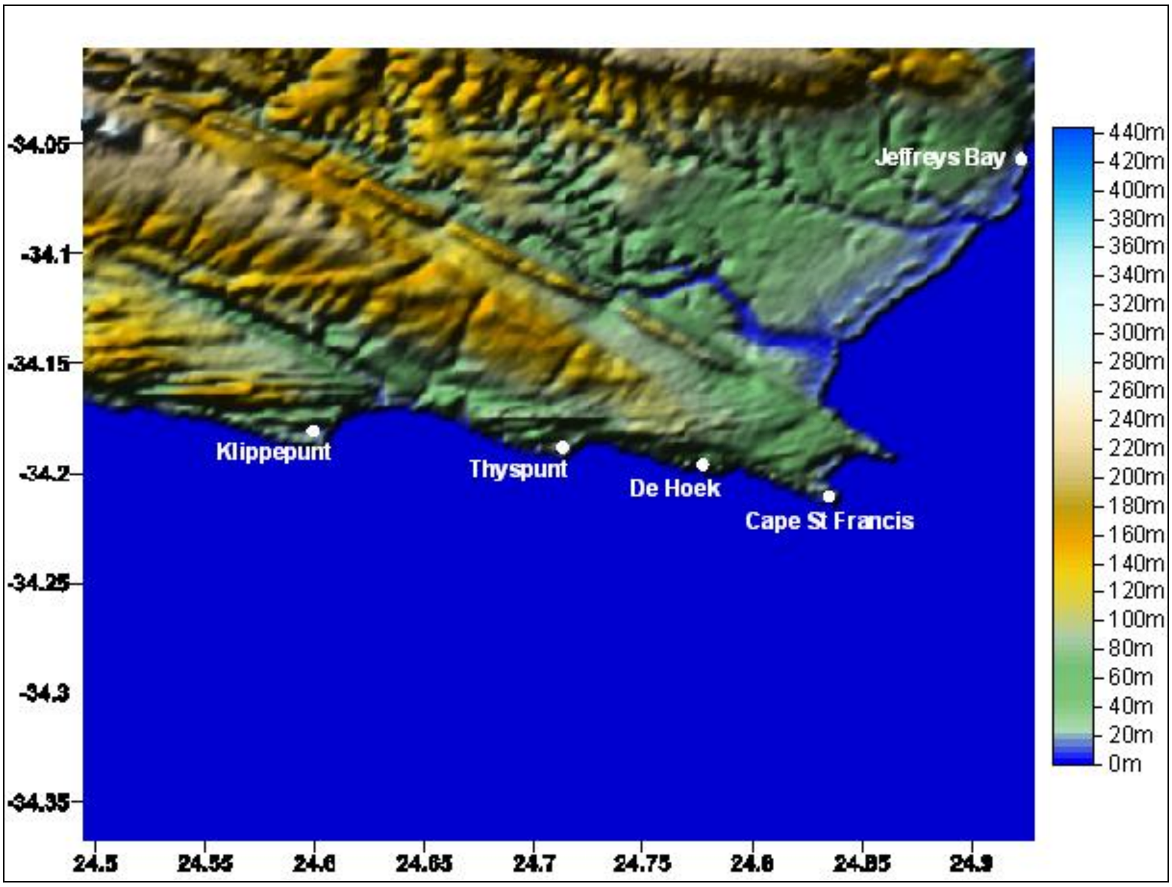


Figure 2-13: Shaded relief profile of the Thyspunt site

2.3 Meteorology

2.3.1 Seasonal Driving Forces

This section provides the background for the seasonal characteristics observed at the three sites of interest. South Africa is located in the dry subtropics of the Southern Hemisphere. According to planetary forces as a result of equatorial-polar temperature (pressure) gradients and the rotation of the Earth, the subtropics is dominated by subsidence of air and high pressures in the lower atmosphere, which results in stability and droughts. It is therefore important to note that prevailing droughts are the norm in the subtropics, and that rainfall only occurs because of radiation disturbances in the predominantly dry subtropics. Atmospheric circulation patterns that lead to rainfall over South Africa can therefore be seen as disturbances in the dry subtropical circulation. These disturbances are normally in the form of continental low pressure systems formed by continental heat radiation in the dry high pressure dominated subtropics.

The most important driving force for these seasonal disturbances over South Africa is land surface radiation. During summer months the South African continent radiates more energy towards the atmosphere than most of the surrounding ocean, meaning that lower pressures and convection will develop over the continent. This coincides with clockwise rotation (see Figure 2-14) which "draws" moist tropical air towards the south by means of a band of clouds extending from the north-west to the south-east.

This mechanism, also known as a tropical temperate trough, is the most important reason for the occurrence of summer rain over the eastern parts of South Africa. There are obviously variations in the strength and location of low pressure systems in relation to the surrounding higher pressures in the day-to-day weather of South Africa.

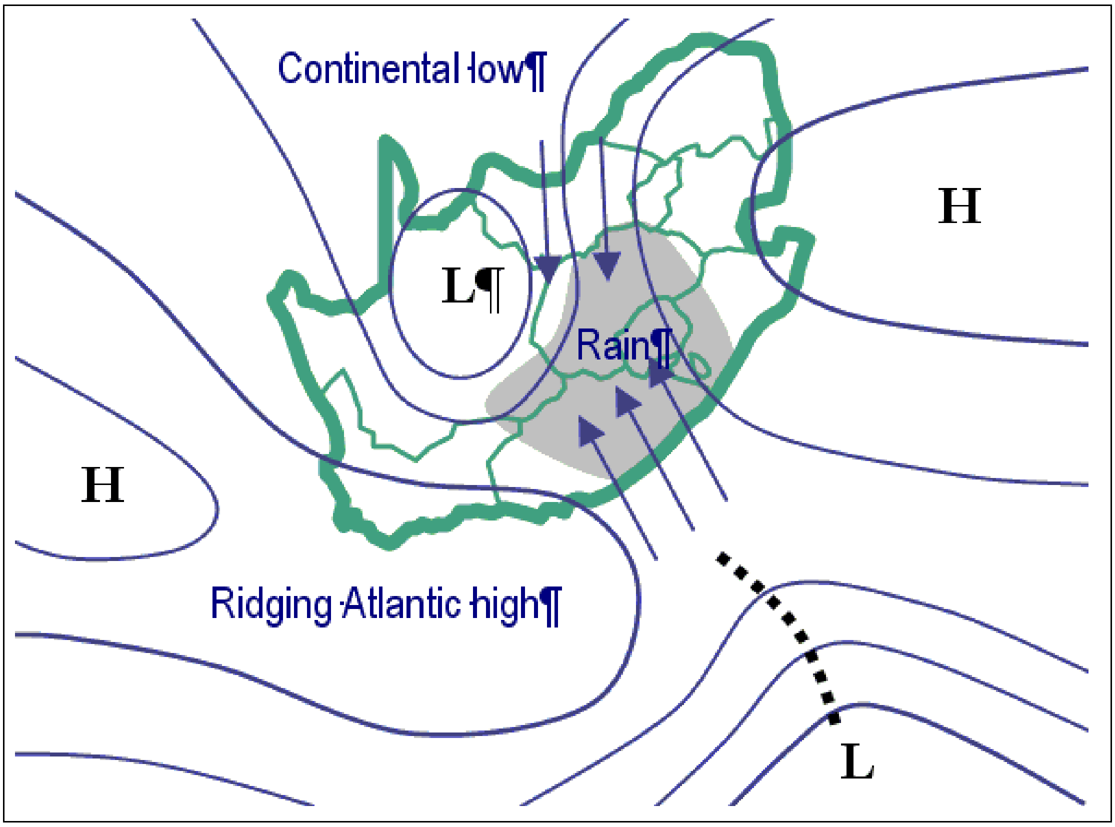


Figure 2-14: Rainfall over South Africa is caused by continental atmospheric pressure disturbances. During summer months continental radiation allow for the formation of clockwise continental lows which draws moist air from the tropics towards the eastern parts of South Africa

Predominantly dry conditions over the interior returns during winter months when radiation from the continent's surface declines and the South African region returns to a state of normally dry conditions. However, the southern coastline of South Africa is just far enough south so that cold air masses from the poles (cold fronts) manage to sweep from west to east over the ocean and adjacent southern coastline of the African continent. During winter months cold fronts might even propagate over the continent, and with the Indian Monsoon, might transfer cold air as far north as Kenya. With enough moisture in the atmosphere, cold fronts might instigate cloud development and rainfall, since the cold heavy air mass serves as an obstacle against which warmer moist air might lift to allow for adiabatic cooling, condensation and eventually rain. It is this process that brings most of the winter rain to the Western Cape.

Cold fronts propagate from west to east over the interior (mostly winter) or southern tip or southern ocean (mostly summer) of South Africa throughout the year. These fronts are normally followed by cold heavy air with high pressure values. When a cold front passes, the pre-frontal high pressure region might link up with the Atlantic High which is normally located to the west of the country over the Atlantic Ocean. On a weather map such conditions are referred to as a ridging high. Ridging highs (or anticyclones) are main reason for onshore air flow along the southern and eastern coast line of South Africa, which might develop in rainfall when topographic lift takes place along the continental escarpment.

The climate of a region is formed by a sequence of individual weather events. It is sometimes more appropriate to consider individual weather events when analysing the climate of a region because extreme weather is often been smoothed by climate averages. These events are described in more appropriate detail in Section 3.3.2, with the discussion of long range trajectories.

2.3.2 Atmospheric Stability

The atmospheric boundary layer constitutes the first few hundred metres of the atmosphere. This layer is directly affected by the earth's surface, either through the retardation of flow due to the frictional drag of the earth's surface, or as result of the heat and moisture exchanges that take place at the surface. During the daytime, the atmospheric boundary layer is characterised by thermal turbulence due to the heating of the earth's surface and the extension of the mixing layer to the lowest elevated inversion. Radiative flux divergence during the night usually results in the establishment of ground-based inversions and the erosion of the mixing layer. Nighttimes are characterised by weak vertical mixing and the predominance of a stable layer. These conditions are normally associated with low wind speeds, hence less dilution potential.

The most widely used atmospheric dispersion models have generally been based on the assumption that air pollutants behave according to a Gaussian probability distribution. Furthermore, these dispersion models have relied on the atmosphere being classified into one of six or seven stability classes suggested by Pasquill (1961) and later modified by Gifford (1962). These are described as follows:

Stability Class	Atmospheric Condition
A	Very unstable or convective conditions. Calm wind, clear skies and hot daytime conditions.
B	Moderately unstable. Clear skies, daytime conditions
C	Unstable conditions. Moderate wind, slightly overcast daytime conditions.
D	Neutral atmospheres. Strong winds or cloudy days and nights.
E	Stable conditions. Moderate wind, slightly overcast night-time conditions.
F	Moderately stable conditions. Low winds, clear skies, cold night-time conditions
G	Very stable conditions. Calm winds, clear skies, cold night-time conditions

The largest difference between the different atmospheric stability classes can be observed in the vertical plume behaviour, as shown in Figure 2-15. The difference is closely related to the vertical temperature gradient (i.e. lapse rate), as shown in the figures. During unstable condition, the air temperature decreases with height (i.e. negative lapse rate), whereas during stable conditions, the lapse rate is positive. When the lapse rate is near the dry adiabatic lapse rate of 0.98°C drop in temperature for every 100 m vertical rise, the atmosphere is considered to be neutral.

With very stable conditions, the plume is relatively thin in the vertical, whereas during very unstable conditions, the plume follows a looping behaviour, resulting in a more dilute, but much wider (in the vertical) plume. As a result, for elevated releases, the highest ground level concentrations would occur during unstable, daytime conditions. The wind speed resulting in the highest ground level concentration depends on the plume buoyancy. If the plume has considerable buoyancy (high exit gas velocity and temperature) together with a low wind, the plume will reach the ground relatively far downwind. With stronger wind speeds, on the other hand, the plume may reach the ground closer, but due to the increased ventilation, it would be more diluted. A wind speed between these extremes would therefore be responsible for the highest ground level concentrations.

Stable conditions normally result in high ground level concentrations for low level releases, e.g. fugitive emissions from material handling operations. Air pollution episodes frequently occur just prior to the passage of a frontal system, which is characterised by calm winds and stable conditions.

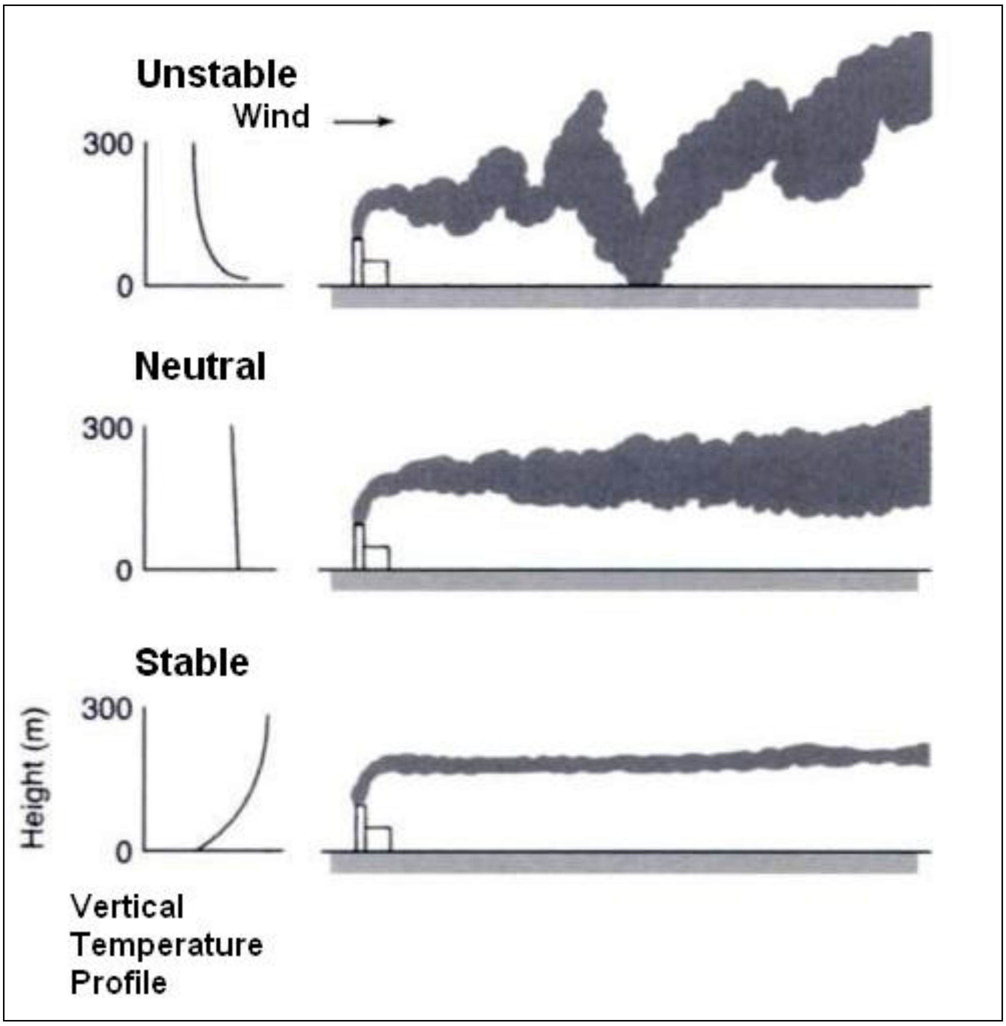


Figure 2-15: Effect of atmospheric turbulence on plume behaviour (after Oke, 1987)

2.3.3 Local Meteorology

The horizontal dispersion of pollution is largely a function of the wind field. The wind speed determines both the distance of downward 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.

The local wind field is normally described by wind roses. Wind roses comprise 16 spokes, which represent the directions from which winds blew during the monitoring period. The colours/shades of gray or box width reflect the different categories of wind speeds, the box closest to the inner circle, for example, represent winds of 1 m/s to 2 m/s. The dotted circles provide information regarding the frequency of occurrence of wind speed and direction categories. For the current wind roses, each dotted circle represents 5% frequency of occurrence. The figure given in the centre of the circle describes the frequency with which calms occurred, i.e. periods during which the wind speed was below 1 m/s. These observations were made with RM Young U and V anemometer sensors at an effective height of 10 m above ground level. All speeds are given in m/s.

(a) Duynefontein

(i) Wind Field

The wind roses reflecting day and night-time conditions are given in Figure 2-16, together with the wind rose combining all hours of the wind analysed from the wind record (2002 to 2007). The wind regime largely reflects the synoptic scale circulation. The flow field is dominated by south-easterly wind, clearly reflecting the South Atlantic High Pressure anticyclonic circulation which dominates the region throughout much of the year. Differential heating and cooling of the air along the coastline (due to the ocean and land mass) provides a characteristic diurnal shift in the wind field. Calm periods with an increase in east-northeasterly off-shore flow are more prevalent during the night-time. In contrast, an increase in westerly flow (on-shore winds) is observed during day-time conditions.

During winter months (July to August), an increase in frequency of east-northeasterly winds occur (Figure 2-17). An increase in the frequency of southerly winds during summer months (December to February) is observed with a greater number of moderate to strong winds (5 - 10 m/s). Autumn months are associated with a greater frequency of calm wind conditions, with the smallest number of calms occurring during winter and spring months. Note the high percentage of winds from the southerly sector in summer in contrast to the northerly winds, which dominate in winter.

South-south-easterly winds dominate, with approximately 13% occurrences during a year. This wind direction also experiences the highest frequency of strong winds, i.e. winds in excess 12 m/s occurring 0.2% of the year. Although most of the strong winds occur from the south to south-easterly sector (~1.5% above 10 m/s), relatively frequent strong winds are also evident from the west-north-west to the north-north-west (~0.3% above 10 m/s). Winds from the north-east to easterly sector are average the lowest (~2.5 m/s), compared to the average of 5.6 m/s from the south to south-easterly sector. The average wind speed of the west-north-west to the north-north-west sector is about 4.4 m/s.

Table 2-1 is a summary of highest wind speeds recorded at Duynefontein for the period 1980 to 2007. The site experienced exceptionally strong winds (tornadoes/waterspouts) in May 1987 (highest gust of 38.3 m/s) caused by thunderstorm cells in well-developed mid-latitude cyclones (cold fronts) (SAWS 1991).

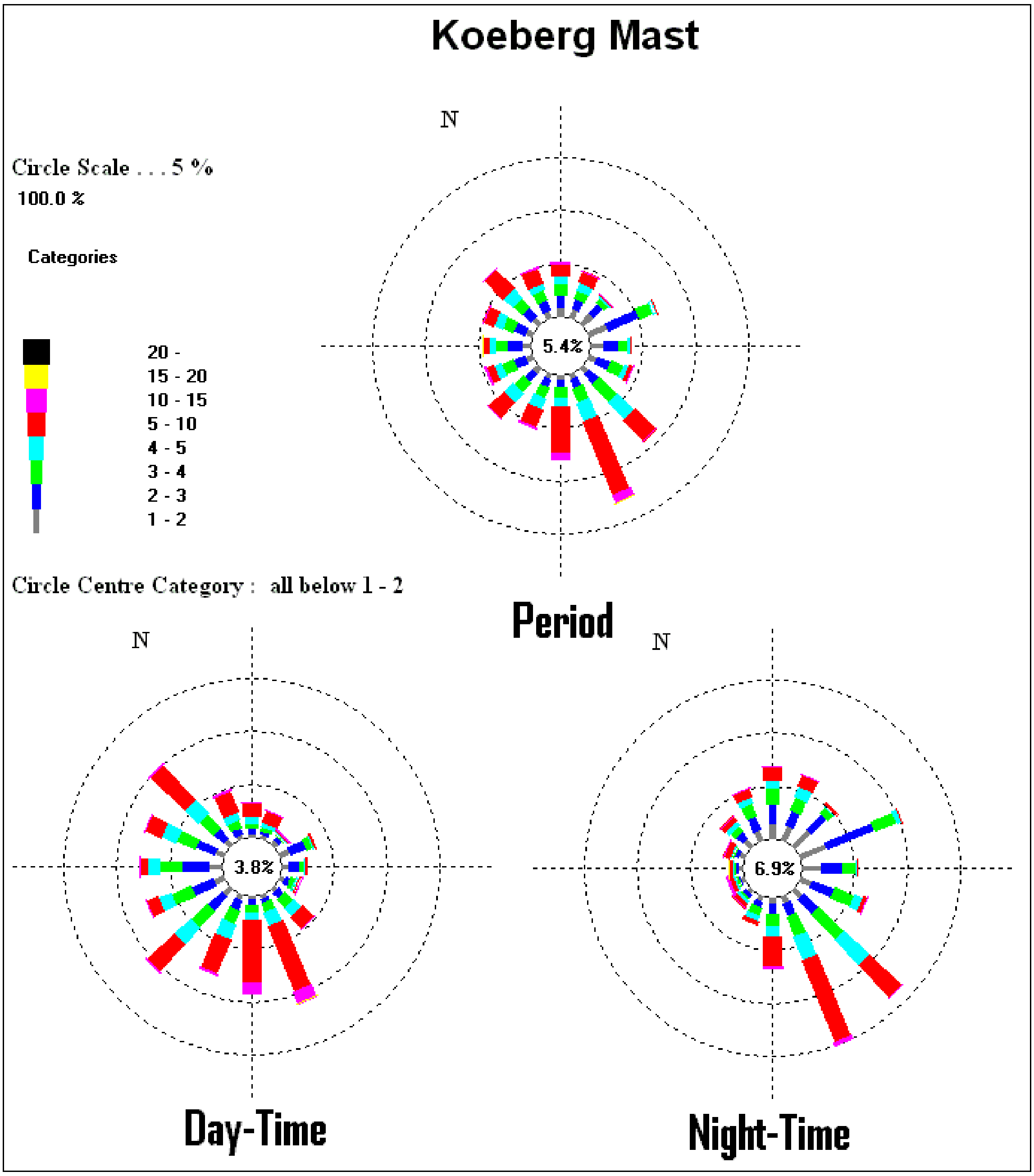


Figure 2-16: Period, day- and night-time wind roses for Duynefontein site

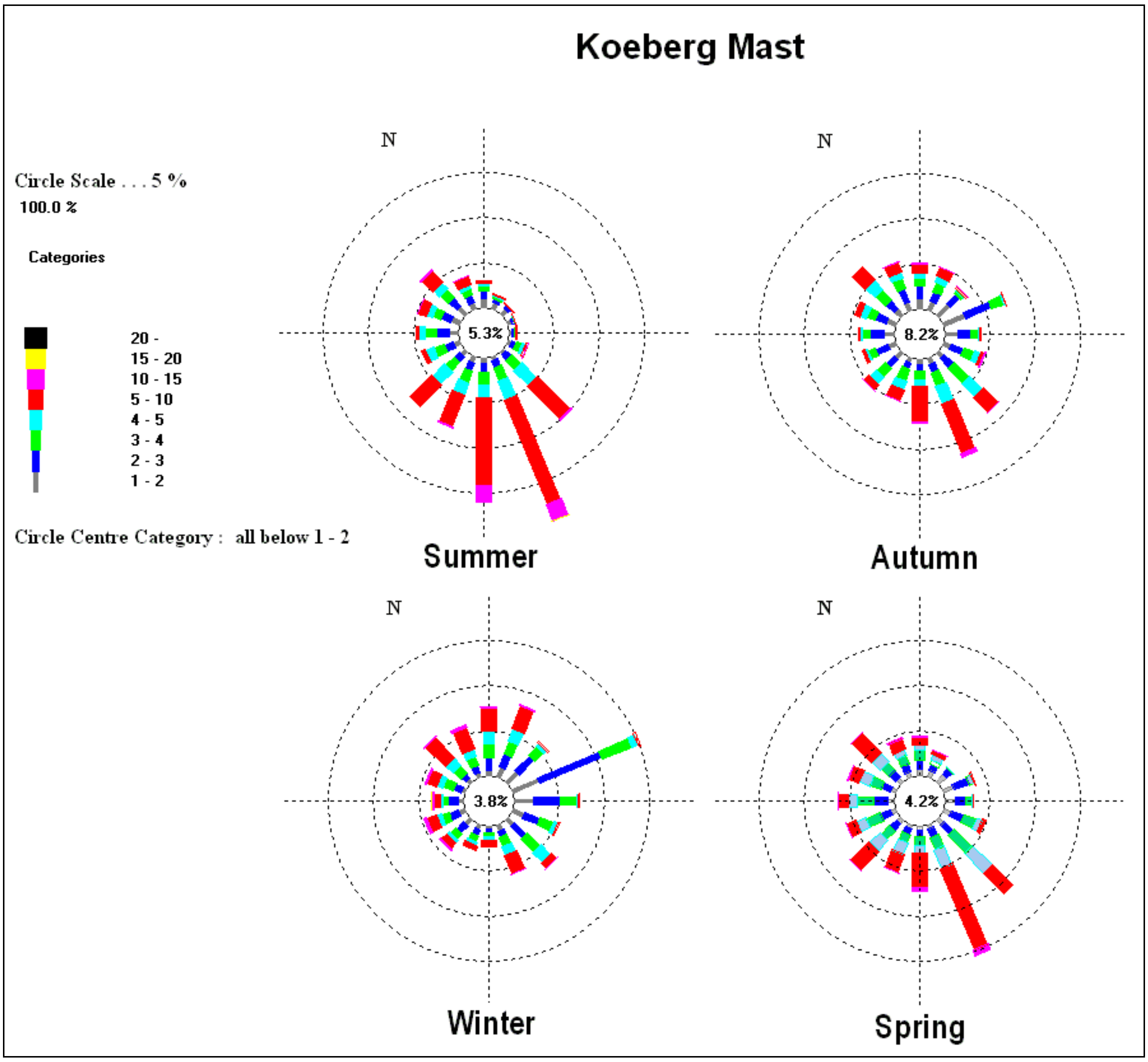


Figure 2-17: Seasonal wind roses for Duynefontein site

Table 2-1: Highest wind gusts measured at Duynefontein: 1980 to 2007

Month	Wind Gust (m/s)	Wind Bearing	Year of Occurrence
January	30.2	NNW	1986
February	28.8	NNW	1987
March	32.0	NNW	1987
April	37.1	S	1987
May	38.3	WSW	1987
June	35.9	E	1986
July	30.6	W	2000
August	31.5	W	1995
September	30.6	W	1991
October	27.2	NNW	1986
November	27.8	SSE	1991
December	36.9	ESE	2003

(ii) Atmospheric Stability

Dispersion parameters for use in Gaussian dispersion models have been derived for each of these classes based on experimental studies (Pasquill, 1961 and Gifford, 1962). However, more recent atmospheric dispersion models do not necessarily rely on the definition of discrete classes, but instead derive continuous dispersion parameters. Nonetheless, the frequency of stability classes have been derived from the 120 m mast measurements for the period 1998 to 2006, and summarised in Table 2-2. Both the vertical temperature gradient ("delta-T") method and the standard deviation of wind direction ("sigma theta") methods are included in the table. The sigma theta was measured at 50 m above ground level.

Table 2-2: Atmospheric stability class frequency

Stability Class	Summer		Winter		Annual	
	Delta-T Method	Sigma Theta Method	Delta-T Method	Sigma Theta Method	Delta-T Method	Sigma Theta Method
A	11.1%	6.8%	3.1%	8.2%	7.1%	7.5%
B	3.3%	3.2%	1.9%	4.1%	2.6%	3.6%
C	3.4%	6.3%	2.5%	7.4%	2.9%	6.8%
D	24.3%	14.9%	24.5%	17.2%	24.4%	16.0%
E	37.7%	52.1%	34.0%	46.0%	35.8%	49.1%
F	13.6%	15.4%	15.2%	15.5%	14.4%	15.5%
G	6.6%	1.3%	18.8%	1.7%	12.7%	1.5%

Atmospheric stability can be determined by the magnitude of change in the ambient temperature between vertical levels of the atmosphere, known as the "delta-T method". The two temperature measurement levels of the onsite meteorological station at Koeberg are 10 and 48.4 m. On an annual basis, the highest frequency of stability class occurrence is neutral (30.7%) followed by slightly stable (26.1%). The mean wind speeds with these two stability classes are 3.1 m/s and 2.3 m/s, respectively. Extremely unstable conditions occur 20% of the time with a mean wind speed of 3.2 m/s, while extremely stable conditions occur only 5.5% of the time with a mean wind speed of 1.3 m/s.

According to the Sigma Theta method, the most frequent classes are stable (E) (36.2%) and very stable (F) (33.98%). The mean wind speeds during these two atmospheric conditions are 6.5 m/s and 6.9 m/s, respectively. The wind mean wind speeds for A, B, C, D and G are 1.8 m/s, 2.85 m/s, 3.43 m/s, 4.34 m/s and 7.02 m/s, respectively.

(iii) Ambient Air Temperature

As indicated in Table 2-3, dry-bulb temperatures measured at Duynefontein site are largely influenced by the close proximity of the cold ocean current which has a moderating effect on the temperatures. The temperatures are measured at a height of 10 m, which also has a moderating effect. The lowest temperature recorded at the Duynefontein site was above freezing (2.2°C on 2 August 1981) and the maximum was 38.2°C (13 September 2005).

Table 2-3: Means and extremes of dry-bulb temperature at the Duynefontein site measured at 10 m above ground level (1980 to 2007)

Month	Average Daily Maximum (°C)	Extreme Maximum (°C)	Average Daily Minimum (°C)	Extreme Minimum (°C)
January	25.4	38.1	15.9	10.5
February	25.5	38	16.1	9
March	24.3	36.6	15.3	9
April	21	35.5	13.3	5.5
May	19.1	33.6	11	5.7
June	19.4	31.4	9.6	4.1
July	19.5	29	9.2	2.8
August	17.2	32	8.2	2.2
September	19.7	38.2	10.4	2.3
October	20.4	37.2	11.6	5.4
November	22.6	36.3	13.6	6.3
December	22.9	37.4	14.5	9.3
Annual	21.4	38.2	12.4	2.2

Historical records of ambient dry bulb air temperature recorded at Cape Town International Airport report on an extreme maximum temperature of 40.7°C (1956-1973) and an extreme minimum temperature of -1.3°C. This weather station is located inland and therefore not as much influenced by the close proximity of the cold ocean current than at the Duynefontein site. The ocean current has a moderating effect on the temperatures: the lowest dry-bulb temperature recorded at Duynefontein site is above freezing (2.2°C on 2 August 1981) and the maximum is 38.2°C (13 September 2005).

(iv) Solar Radiation

Solar radiation measurements have historically not formed part of the meteorological network at Koeberg. In the absence of this measurement, the dispersion model would calculate the theoretical solar radiation as a function of the time of year and time of day. Realistic values can however only be obtained if the cloud cover is also available. Although the network has recently been extended to include this, the data were considered too limited to include in this study (August 2008). Systematic Solar radiation measurements in southern Africa started in the 1950s. Clemence (1992) used over 20 000 daily radiation observations from a wide geographic range of stations, and derived a relationship for southern Africa to estimate solar radiation from:

- Extraterrestrial radiation;
- Maximum daily temperature; and
- Temperature range.

Schulze (1997) used this information and produced monthly maps for South Africa, as shown in Figure 2-18 (January / midsummer) and Figure 2-19 (July / midwinter).

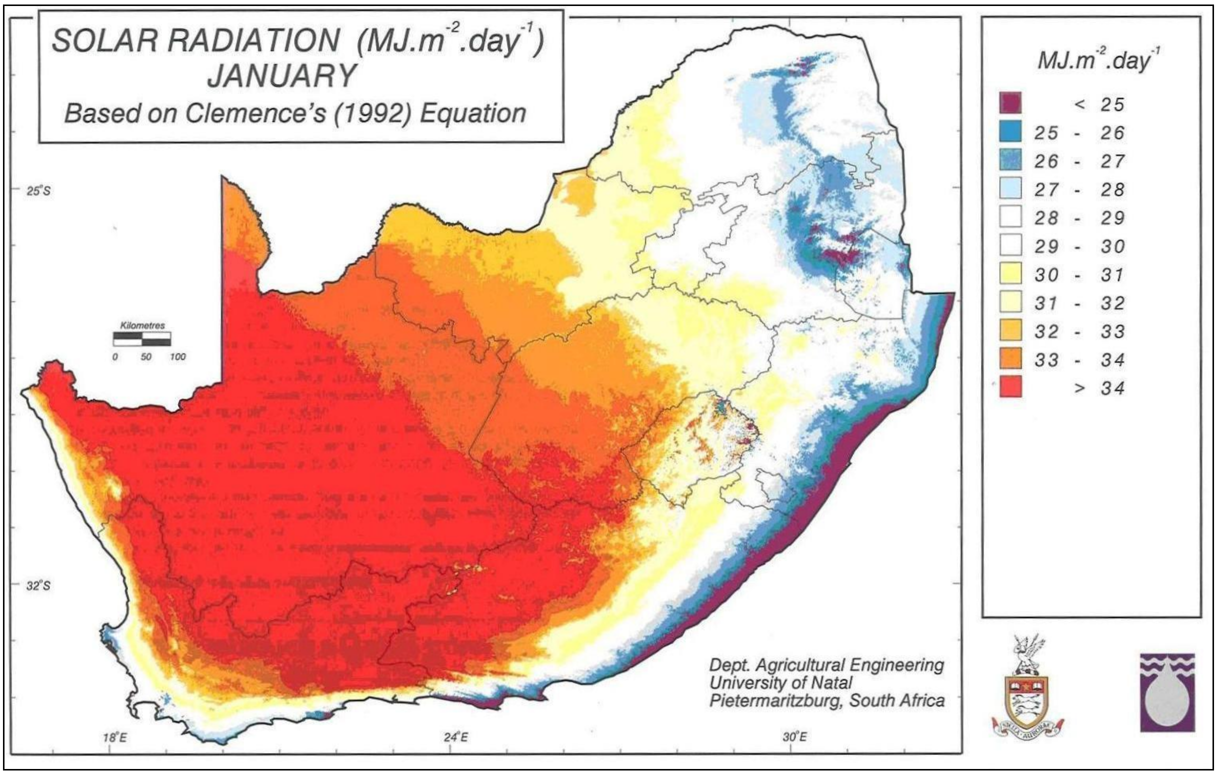


Figure 2-18: Solar radiation map of South Africa for January (Schulz 1997)

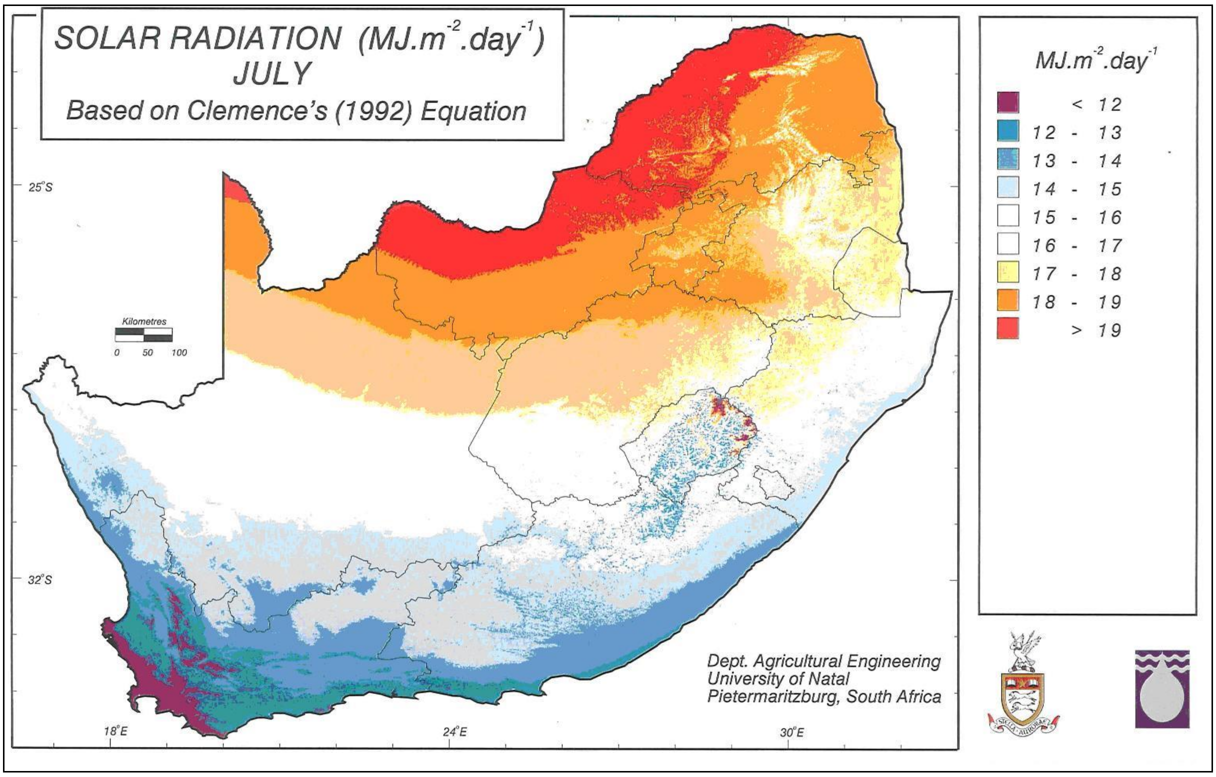


Figure 2-19: Solar radiation map of South Africa for July (Schulz 1997)

Using this data, a summary of the monthly variations of daily solar radiation in the Western Cape is provided in Table 2-4.

Table 2-4: Solar Radiation ($MJ.m^{-2}.day^{-1}$) for the Western Cape (Schulze 1997)

Month	Mean Value	Maximum Value	Minimum Value
January	33.6	37.3	22.3
February	30.4	34.3	20.5
March	25.2	28.3	17.8
April	19.6	21.6	13.2
May	14.8	16.6	10.2
June	12.5	13.9	8.8
July	13.3	15.1	9.0
August	16.8	19.2	10.8
September	22.0	25.1	13.9
October	27.9	32.0	17.2
November	32.1	36.5	20.6
December	33.9	38.3	22.7

(v) Atmospheric Moisture

No record of relative humidity could be obtained for Duynefontein.

(vi) Precipitation

The rainfall season for the Duynefontein site is classified as a winter rainfall season area (Figure 2-20). Precipitation falls throughout the year but generally summers are dry while the winters are wet. This pattern is typical of the Mediterranean type climate regions of the world.

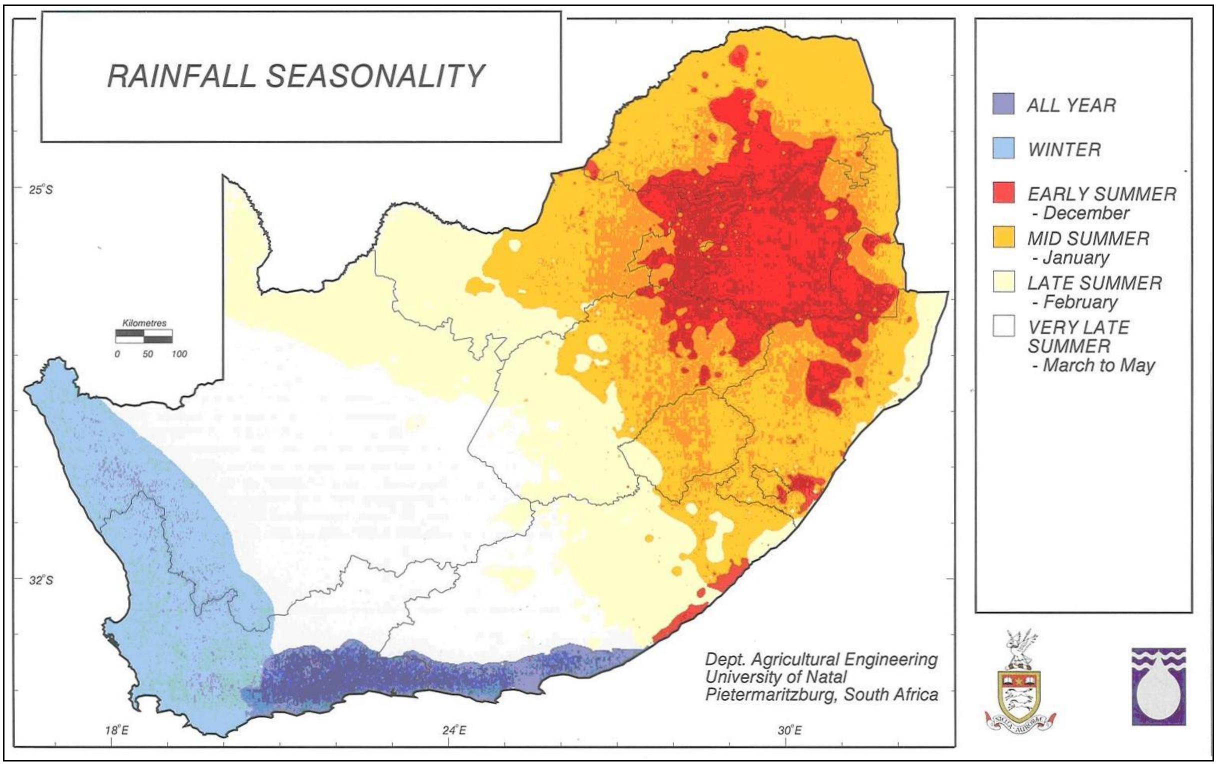


Figure 2-20: Rainfall seasonality for South Africa (Schulze 1997)

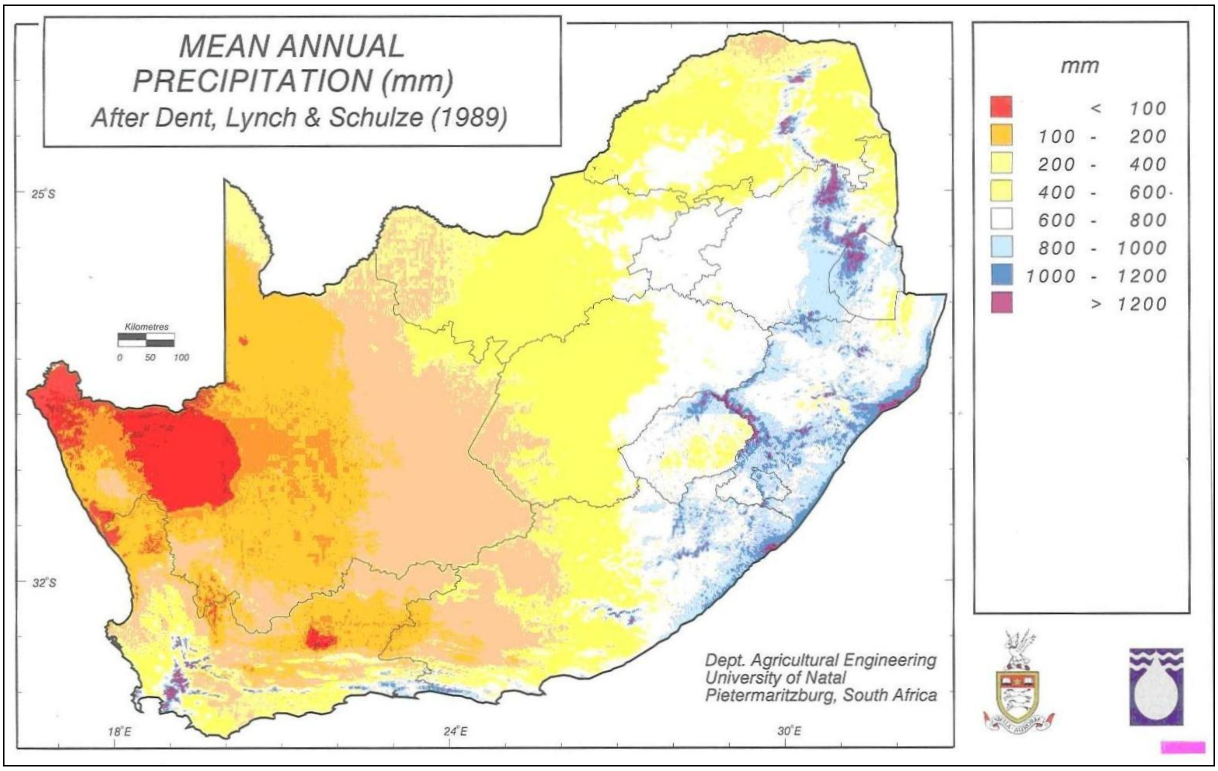


Figure 2-21: Mean annual precipitation for South Africa (Schulze 1997)

The Mean Annual Precipitation (MAP) characterises the long-term quantity of water available to a specific region. The MAP for South Africa is shown in Figure 2-21. According to the figure, the MAP lies between 200 mm and 400 mm. Actual recordings made at Duynefontein for the period 1980 to 2007 are summarised in Table 2-5. The annual average recording for this period is 374.8 mm.

Table 2-5: Monthly measurements of precipitation at the Duynefontein Site (1980 to 2007)

Month	Average Monthly (mm)	Maximum Monthly (mm)	Minimum Monthly (mm)
January	10.3	67.6	0.0
February	8.1	42.0	0.0
March	13.0	48.4	0.0
April	34.6	107.8	2.8
May	46.9	98.2	1.3
June	65.0	157.4	12.0
July	65.3	162.4	22.8
August	54.0	134.4	12.8
September	32.7	75.0	2.5
October	19.0	114.8	0.6
November	12.3	52.4	0.4
December	13.5	32.8	0.3
Total	374.8	162.4	0.0

Table 2-6 provides the highest and lowest 24-hour rainfall maximums recorded from midnight to midnight. The highest recording is 58.2 mm, which was measured on the 14 June 1996.

Table 2-6: 24-Hourly maximum precipitation measured at the Duynefontein Site (1980 to 2007)

Month	Highest 24-hour Maximum (mm)	Lowest 24-hour Maximum (mm)
January	57.4	0
February	26.4	0
March	33.8	0
April	62	1.4
May	49.3	1.2
June	58.2	4.8
July	70	8.4
August	57.6	5
September	34.6	2.5
October	50.4	0.5
November	21.6	0.4
December	17	0.2

Rainfall records of observations at Cape Town International Airport for the period 1938 to 1972 conclude a maximum rainfall rate of 61.7 mm for a 24-hour period, measured from midnight to midnight, The highest rainfall rate recorded for 15-, 30-, 45- and 60-minute periods are 16 mm, 28.8 mm, 36.3 and 39.1 mm, respectively. In comparison, the maximum amount of rainfall recorded at Duynefontein in a 24-hour period is 58.2 mm, measured on the 14 June 1996.

(vii) Thunder and Hail

Thunder and hail are not recorded at the Duynefontein site. Records of thunder and hail obtained from the weather office at Cape Town International Airport are presented in Table 2-7.

Table 2-7: Average frequency of thunder and hail measured at Cape Town International Airport: 1956 to 2004

Month	Average number of days with thunder	Average number of days with hail
January	0.2	0.0
February	0.6	0.1
March	0.8	0.0
April	0.8	0.1
May	0.9	0.2
June	0.8	0.2
July	0.7	0.2
August	0.7	0.0
September	0.4	0.0
October	0.5	0.1
November	0.5	0.0
December	0.4	0.0
Annual	7.3	0.9

(viii) Snow and Frost

Although there has been no evidence of snow at the Duynefontein site, records obtained from Cape Town International Airport indicate that there is a possibility

(Table 2-8). Frost has been observed on occasions during the months of June until late August.

Table 2-8: Average Frequency of frost and snow measured at Cape Town International Airport: 1956 to 2004

Month	Average number of days with Frost (Temperature below 0°C)	Average number of days with Snow
January	0.0	0.0
February	0.0	0.0
March	0.0	0.0
April	0.0	0.0
May	0.0	0.0
June	0.2	0.0
July	0.2	0.0
August	0.1	0.1
September	0.0	0.0
October	0.0	0.0
November	0.0	0.0
December	0.0	0.0
Annual	0.5	0.1

(ix) Fog

No record of fog occurrences exist at the Duynefontein site, but being situated on the coast, fog is a regular occurrence during the passage of a coastal low as it migrates south along the West Coast, around the peninsula and eastwards along the Southern Cape Coast.

Table 2-9: Average frequency of fog measured at Cape Town International Airport: 1956 to 2004

Month	Average Number of Days with Fog				
	Cape Town International Airport	Dassen Island		Cape Point	
	1961 to 2004	1893 to 1956	1988 to 2004	1961 to 1990	1991 to 2004
January	1	6	6	7	5
February	2	9	5	8	6
March	3	9	8	10	7
April	6	9	7	10	7
May	7	4	7	8	7
June	6	4	2	7	3
July	7	4	1	7	3
August	3	3	2	6	3
September	3	2	2	7	4
October	2	5	1	7	3
November	2	4	2	8	3
December	1	5	3	8	5
Annual	43	64	46	93	56

During the summer the fog normally burns off very quickly but in winter the fog stays around till noon and moves in again just before the sun sets.

Records of fog obtained from the South African Weather Services are given in Table 2-9 and are shown for Cape Town International Airport, Cape Point, and Dassen Island. Days are considered ‘foggy’ if the maximum horizontal visibility is less than 1 km. This does not include shallow fog, which has a depth of less than 2 m on land and 15 m on the sea.

(x) Evaporation

No record of relative humidity could be obtained for the Duynefontein site. Instead estimated values were obtained from Shulze (1997) and summarised in Table 2-10. The annual maximum, minimum and mean monthly evaporation rates for the Western Cape Province are 235 mm, 65 mm and 186 mm, respectively. The highest monthly maximum evaporation (401 mm) occurs during January. The rate decreases significantly down to 94 mm in June. The monthly minimum evaporation ranges between 73 mm in December and 50 mm in June.

Table 2-10: Maximum, minimum and mean monthly evaporation for the Western Cape Province (Schulze, 1997).

Month	Monthly Maximum	Monthly Minimum	Monthly Mean
January	401	70	322
February	324	65	254
March	285	73	217
April	187	70	145
May	131	62	104
June	94	50	76
July	102	52	82
August	138	59	106
September	189	65	144
October	256	70	209
November	331	72	258
December	380	73	313
Annual	235	65	186

(b) Bantamsklip

The recording of meteorological data started on site from 9 January 2008. As these data are not sufficient for any long-term analysis, other sources of information were consulted. These include the three-year wind observations for the period 1987 to 1989 at Die Gruis, Buffeljagsbaai and Danger Point. Longer datasets were obtained from the closest weather stations operated by the South African Weather Services (SAWS). The SAWS automatic weather stations included in a 100 km radius from the Bantamsklip site are:

- Hermanus (northwest 44 km);
- Struisbaai (east-northeast 47 km);
- Riviersonderend (north-northeast 72 km);
- Villiersdorp (north-northwest 83 km); and
- Strand (northeast 96 km).

Hermanus (west of the site) and Struisbaai (east of the site) were considered to be more appropriate than the other four stations due to their location along the same coastline as Bantamsklip.

(i) Wind Field

Early recordings done by Eskom (1987 to 1989) indicate that the wind direction in this region is from the west-northwest to northwest. A secondary wind direction is from the east to east-southeast. The observations were typically seen to have an alongshore flow pattern.

Wind roses for Hermanus prepared from SAWS for the period 2001 to 2008 are given in Figure 2-22 and Figure 2-23. The former set of wind roses also include an analysis of the wind data recorded on site at Bantamsklip (January 2008 to September 2009). The wind flow at Hermanus is similar to the Eskom and the Bantamsklip observations, i.e. predominantly east and west. However, there are some subtle differences. The main difference between the Hermanus and the Eskom data is in the increased occurrence of east-south-easterly winds at Danger Point and Buffelsjagbaai. This is also clearly shown in the observations made at the Bantamsklip site.

The day and night-time wind roses for Bantamsklip in Figure 2-22 clearly illustrates the differential heating and cooling of the air along the coastline, which provides the characteristic diurnal shift in the wind field. Increased south and south-south-easterly (on-shore) winds during the day are typical of the sea breeze conditions created by rising air over the land. Calm periods with an increase in north and north-westerly off-shore flow are more prevalent during the night-time.

According to the Bantamsklip observations, albeit only 21 month’s data, east-north-easterly winds dominate, with approximately 16.6% occurrences during this period. Although this wind direction experiences a high frequency of strong winds, i.e. winds in excess 10 m/s occurring 1.6% of the period, the strongest winds are from the west-south-west, with 0.02% above 15 m/s. Relatively frequent strong winds are also evident from the west-north-west (~0.01% above 15 m/s). Winds from the north-north-east to northerly sector are on average the lowest (~2 m/s), compared to the average of 5.4 m/s from the east-north-east to south-east-east and west-south-west to west-north-west sectors.

During winter months (July to August), an increase in the frequency of east-orth-easterly winds occur (Figure 2-23 and Figure 2-24). An increase in the frequency of westerly winds during summer months (December to February) is observed with a greater number of moderate to strong winds (5 - 10 m/s). Autumn months are associated with a greater frequency of calm wind conditions (12.6%), with the smallest number of calms occurring during spring and summer months.

Table 2-11 is a summary of highest wind speeds recorded at Bantamsklip for the period January 2008 to September 2009. The site experienced exceptionally strong winds during May 2009 (highest gust of 31.6 m/s).

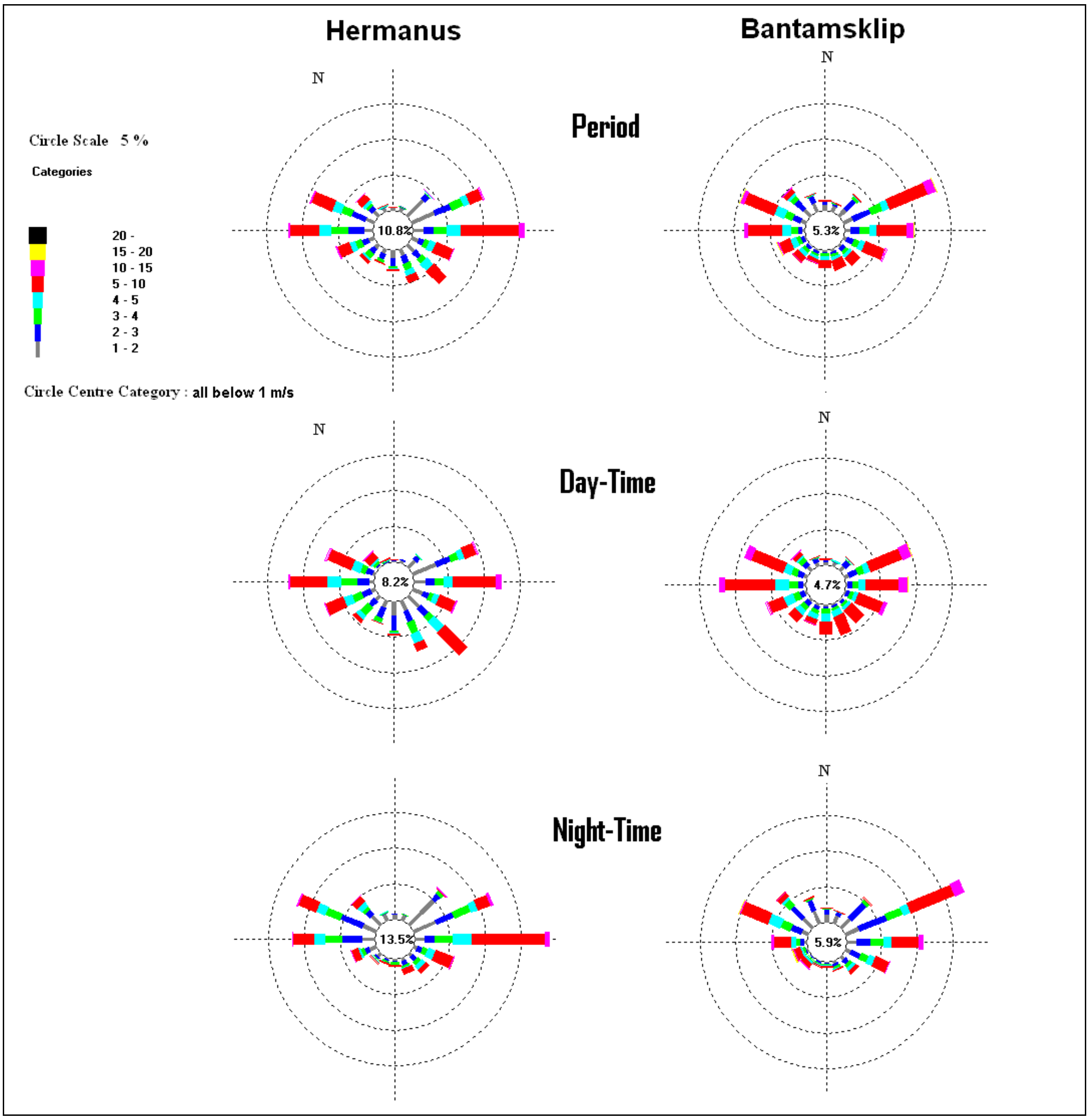


Figure 2-22: Comparison of wind roses between Hermanus (SAWS, 2001 to 2008) and onsite, Bantamsklip (January 2008 to September 2009) data

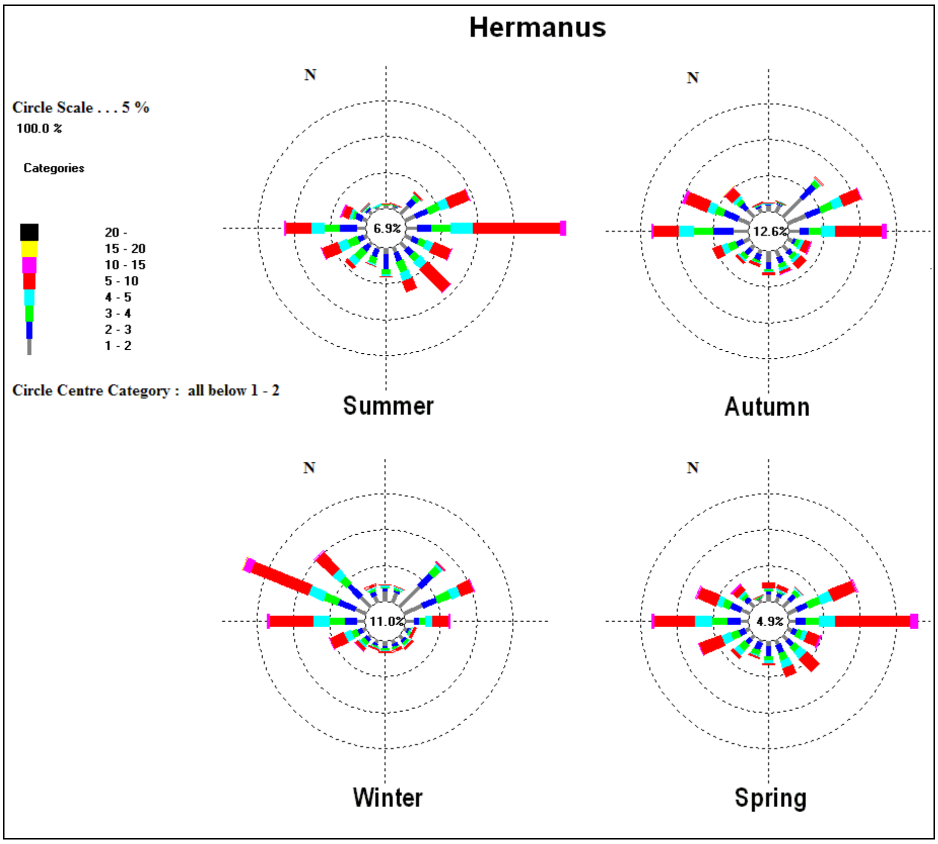


Figure 2-23: Seasonal wind roses for Hermanus (SAWS, 2001 to 2008)

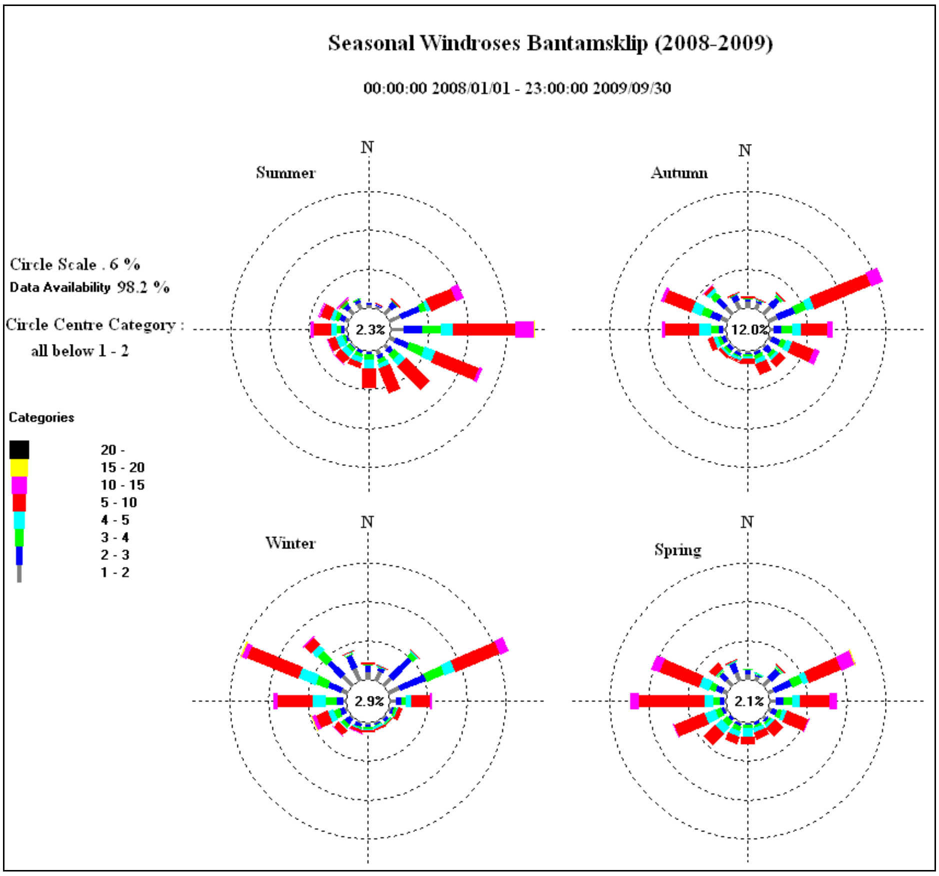


Figure 2-24: Seasonal wind roses for Bantamsklip (January 2008 to September 2009)

Table 2-11: Highest wind gusts measured at Bantamsklip (January 2008 to September 2009)

Month	Wind Gust (m/s)	Wind Bearing
January	20.9	WNW
February	21.6	E
March	20.1	ENE
April	20.7	E
May	31.6	WSW
June	28.5	WSW
July	20.6	WNW
August	24.9	WSW
September	21.9	WNW
October	30.4	SSE
November	20.1	ENE
December	30.4	W

(ii) Atmospheric Stability

Atmospheric stability was calculated according to the “Sigma Theta” method. (The “Delta-T” method, which was the additional method used to estimate stability at the Duynefontein site, requires two temperature readings at different vertical heights on a tall mast. This information is not currently available on the 10 m mast at the site). On an annual basis, the highest frequency of stability class occurrence is neutral (58.7%) followed by slightly stable 16.0%. The mean wind speeds with these two stability classes are 5.8 m/s and 5.7 m/s, respectively. Extremely unstable conditions occur 5.3% of the time with a mean wind speed of 2.2 m/s, while extremely stable conditions occur only 7.0% of the time with a mean wind speed of 1.2 m/s.

(iii) Ambient Air Temperature

The recorded dry-bulb temperatures at Bantamsklip for the period January 2008 to September 2009 is summarised in Table 2-12. The highest maximum temperature (33.2 °C) was recorded during March 2008 with the lowest (2.8 °C) during September 2009.

Table 2-12: Dry-bulb temperature observations at Bantamsklip (January 2008 to September 2009)

Month	Daily Average (°C)	Daily Maximum (°C)	Daily Minimum (°C)
January	20.3	30.1	11.9
February	20.2	32.7	10.2
March	19.4	33.2	8.9
April	17.0	33.2	9.5
May	16.2	30.5	7.9
June	14.0	26.0	6.2
July	13.1	26.8	4.5
August	13.4	27.9	3.6
September	13.8	32.4	2.8
October	15.6	25.5	5.8
November	17.0	28.4	8.1
December	19.4	29.1	8.6

The ambient air temperature statistics for Hermanus and Struisbaai are included for comparison. These are summarised in Table 2-13 and Table 2-14, respectively. Albeit a short record length, in comparison to Hermanus, it would appear that the ambient temperatures at Bantamsklip are similar for the summer months, but slightly lower for the winter months.

The average daily maximum and minimum temperatures recorded at Hermanus were 23.4°C (January) and 10.5°C (August). In comparison, the average daily maximum and minimum temperatures recorded at Struisbaai were 24.1°C (February) and 8.7°C (July).

The extreme maximums at Hermanus and Struisbaai were 33.2°C (October) and 32.6°C (October), respectively. The extreme minimums at Hermanus and Struisbaai were 4.8°C (July) and 1.7°C (July), respectively.

Table 2-13: Means and extremes of dry-bulb temperatures for Hermanus for the period 2001 to 2007

Month	Average Daily Maximum (°C)	Extreme Maximum (°C)	Average Daily Minimum (°C)	Extreme Minimum (°C)
January	23.4	32.8	17.2	12.1
February	23.2	30.8	17.2	11.3
March	22.4	30.8	15.8	9.8
April	20.9	30.3	14.3	9.5
May	19.6	32.0	13.1	7.5
June	18.2	31.1	11.2	5.0
July	17.4	29.6	10.6	4.8
August	17.0	30.9	10.5	5.2
September	18.6	31.5	12.5	7.7
October	20.4	33.2	13.9	8.1
November	21.5	29.9	15.3	10.5
December	22.9	30.5	16.7	11.2
Annual	20.5	33.2	14.0	4.8

Table 2-14: Means and extremes of temperature for Struisbaai for the period 2001 to 2007

Month	Average Daily Maximum (°C)	Extreme Maximum (°C)	Average Daily Minimum (°C)	Extreme Minimum (°C)
January	23.8	29.9	18.5	10.2
February	24.1	28.4	19.2	11.4
March	22.8	31.7	17.1	7.7
April	20.3	25.9	14.7	5.6
May	18.7	31.0	11.7	3.2
June	17.1	24.9	8.8	2.0
July	16.5	27.5	8.7	1.7
August	16.4	30.1	8.9	2.1
September	17.7	25.7	11.4	4.0
October	19.1	32.6	13.6	5.9
November	21.0	29.2	15.3	6.6
December	22.8	31.2	17.2	9.5
Annual	20.0	32.6	13.8	11.4

(iv) Solar Radiation

Onsite solar radiation is only available for January to September 2009 In Table 2-15 average daily observations for these months are compared to the estimates made by Schulze (1997), as discussed previously (Figure 2-18 and Figure 2-19). There is a fair agreement between the observed and estimated values. All observations fall within the estimate range.

Table 2-15: Solar Radiation ($MJ.m^{-2}.day^{-1}$) for Bantamsklip

Month	Observed (2008/2009)	Estimate (Schulz 1997)		
		Mean	Maximum	Minimum
January	24.4	33.6	37.3	22.3
February	23.3	30.4	34.3	20.5
March	19.9	25.2	28.3	17.8
April	10.2	19.6	21.6	13.2
May	10.4	14.8	16.6	10.2
June	8.2	12.5	13.9	8.8
July	10.2	13.3	15.1	9.0
August	13.3	16.8	19.2	10.8
September	16.3	22.0	25.1	13.9
October	24.0	27.9	32.0	17.2
November	26.0	32.1	36.5	20.6
December	28.1	33.9	38.3	22.7

(v) Atmospheric Moisture

Relative humidity has been recorded since January 2008. Table 2-16 is a summary of the measurements for the period January 2008 to September 2009. The average relative humidity appears to be around 78% with the lowest recording during June, i.e. 17.7 %.

Table 2-16: Relative humidity measurements at Bantamsklip (January 2008 to September 2009)

Month	Daily Average (%)	Daily Minimum (%)	Daily Maximum (%)
January	76.9	32.0	99.1
February	77.7	29.3	99.3
March	78.1	24.5	99.4
April	77.0	0.0	99.9
May	79.8	23.2	100.0
June	79.2	17.7	99.7
July	77.2	19.2	100.0
August	78.1	25.0	99.9
September	73.1	10.7	99.9
October	77.1	41.0	99.2
November	78.6	29.0	98.8
December	76.8	45.5	98.3

(vi) Precipitation

As shown in Figure 2-20, the rainfall season for the Bantamsklip area is similar to the Duynefontein site, and is classified as a winter rainfall season area. Rainfall observations are made at the SAWS stations in Hermanus and Struisbaai. These are summarised in Table 2-17. The annual average recording for this period is 533.2 mm at Hermanus and 385.9 mm at Struisbaai.

Table 2-17: Average, maximum and minimum monthly precipitation (mm) for Hermanus and Struisbaai for the period 2001 to 2007 (South African Weather Service 2008)

Month	Hermanus			Struisbaai		
	Average Monthly	Maximum Monthly	Minimum Monthly	Average Monthly	Maximum Monthly	Minimum Monthly
Jan	33.2	121.0	7.2	30.5	78.4	5.6
Feb	23.4	37.4	11.2	13.2	33.6	4.8
Mar	20.5	60.6	5.8	20.8	85.4	0.2
Apr	68.7	232.6	21.2	53.4	175.8	19.6
May	50.9	87.4	9.0	36.1	47.2	8.0
Jun	59.1	132.8	11.6	39.7	75.2	15.4
Jul	68.0	111.0	10.4	49.3	94.6	13.4
Aug	73.3	130.6	33.6	47.2	84.4	25.8
Sep	27.9	52.0	0.0	25.3	45.0	9.8
Oct	52.1	131.4	16.4	34.8	98.6	12.8
Nov	33.9	120.2	9.8	20.8	60.6	3.8
Dec	22.2	51.0	6.6	14.8	33.2	3.0
Total	533.2			385.9		

Unfortunately, rainfall measurements at Bantamsklip were only initiated in January 2008. The monthly totals and the highest 24-hourly rates are given in Table 2-18. Although the data are statistically not adequate, the rainfall at Bantamsklip appears to be similar than the recordings at Hermanus, i.e. the total at Bantamsklip for 2008 was 522.4 mm.

Table 2-18: Monthly precipitation recorded at Bantamsklip for January 2008 to September 2009

Month	Month Total (mm)	Highest 24-Hourly (mm)
January	16.7	4.7
February	14.9	4.2
March	16.6	5.0
April	52.5	17.1
May	151.7	35.6
June	75.6	9.0
July	80.1	10.2
August	45.0	12.5
September	51.6	8.6
October	1.3	0.4
November	8.8	1.3
December	7.6	4.0

(vii) Thunder and Hail

Long-term observations at Danger Point were used to represent the average number of days that thunder and hail occur (Table 2-19).

Table 2-19: Average monthly and annual number of days with thunder, hail and snow for Danger Point. (1901-1959)

Month	Thunder	Hail
Jan	0.0	0.0
Feb	0.2	0.0
Mar	0.1	0.0
Apr	0.0	0.0
May	0.4	0.2
Jun	0.5	0.4
Jul	0.4	0.3
Aug	0.6	0.4
Sep	0.4	0.3
Oct	0.1	0.0
Nov	0.5	0.0
Dec	0.1	0.0
Annual	3.3	1.6

(viii) Snow and Frost

Long-term observations at Danger Point were used to represent the average number of days that snow occurs (Table 2-20). No frost data could be obtained.

Table 2-20: Average monthly and annual number of days with snow for Danger Point. (1901-1959)

Month	Frost	Snow
Jan	No data	0.0
Feb	No data	0.0
Mar	No data	0.0
Apr	No data	0.0
May	No data	0.0
Jun	No data	0.0
Jul	No data	0.0
Aug	No data	0.0
Sep	No data	0.0
Oct	No data	0.0
Nov	No data	0.0
Dec	No data	0.0
Annual	No data	0.0

(ix) Fog

Long-term observations at Danger Point were used to represent the average number of days that fog occurs in Table 2-21.

(x) Evaporation

Evaporation rates were calculated for the monitoring period January 2008 to September 2009 (Table 2-22) using the Penman-Monteith[14] equation. This method requires dry bulb temperature, relative humidity, solar radiation and wind speed.

[14] The Penman-Monteith equation predicts the evapotranspiration at a location using daily mean temperature, wind speed, relative humidity, and solar radiation.

Table 2-21: Average monthly and annual number of days with fog for Danger Point (1901-1959)

Month	Fog
Jan	3.2
Feb	4.4
Mar	4.0
Apr	1.2
May	1.5
Jun	1.0
Jul	1.1
Aug	1.9
Sep	1.0
Oct	0.0
Nov	0.9
Dec	1.7
Annual	21.9

`

Table 2-22: Monthly evaporation rate calculated for Bantamsklip for January 2008 to September 2009

Month	Month Total (mm)
January	140.9
February	129.6
March	121.1
April	60.8
May	65.9
June	50.3
July	60.6
August	74.2
September	90.5
October	126.2
November	134.5
December	159.5

(c) Thyspunt

Onsite recording of meteorological data were started on site from 10 January 2008. As these data are not sufficient for any long-term analysis, other sources of information were also consulted. These include wind observations at four sites in the vicinity of Thyspunt, namely De Hoek, Thyspunt, Klippepunt and Brakkeduine for the period December 1986 to September 1989. Unfortunately, vandalism of equipment resulted in limited data recovery. The most appropriate data set was from January 1987 to September 1987. A longer dataset was obtained from Cape St. Francis, which is the closest weather station operated by the SAWS. Additional SAWS automatic weather stations included in a 100 km radius from the Thyspunt site are:

- Patensie (north-northeast 48 km);
- Uitenhage (northeast 78 km); and
- Port Elizabeth (east-northeast 90 km).

(i) Wind Field

From the historical dataset produced by Eskom (1987), it is clear that the most dominant wind direction in this region is from the west northwest to northwest. The western sites of Brakkeduine and Klippepunt are characterised by winds of a greater northerly direction than Thyspunt and De Hoek. Off-shore wind flows occur about 30 % of the time at all the sites. It is important to also note the very low frequency of calm wind conditions (~2 %). More frequent stronger winds come from a west northwest to northwest direction. Some noticeable mild winds also occur from the northeast direction but these are infrequent. The wind speed tends to increase to mid afternoon as the instability is highest at around 14h00. Furthermore, the frequency of frontal systems and coastal low pressure systems forces a variable daily surface wind speed at all the sites. The offshore flow, i.e. northerly winds are characterised by slow wind speeds and somewhat frequent occurrence (much less than the north-westerly winds but noticeable) indicating the effect of land breezes. The occurrence of onshore flow i.e. southerly winds is negligible at all sites in this region.

Although similar wind conditions are evident from the observations made at Cape St. Francis (Figure 2-25), slight differences have been observed between this station and Thyspunt. The most noticeable difference is the lower prevalence of strong easterly winds at Thyspunt, especially during the night-time. There appears to also be more frequent west-north-westerly winds and slightly less westerly winds at Thyspunt. The observations at both cape St. Francis and Thyspunt indicate increased offshore flows at night at Thyspunt with less evidence of onshore winds. The site experiences very few calm wind conditions (~1%), as recorded both at Cape St. Francis and Thyspunt.

According to the 21-month observations at Thyspunt, westerly winds dominate, with approximately 20.5% occurrences during the period. This wind direction also experiences the highest frequency of strong winds, i.e. winds in excess 10 m/s occurring 1.5% of the year. Winds in excess of 15 m/s occur 0.1% of the period. Strong winds in excess of 15 m/s also occur from the west-south-west (~0.03%) and south-west (~0.02%). Winds from the north-north-east to northerly sector are on average the lowest (~3.9 m/s), compared to the average of 6.2 m/s from the east-north-east and eastern sector, and 5.8 m/s from the west-south-west to western sector.

The western wind component is prevalent during all four seasons (Figure 2-23). However, the eastern wind component is more prevalent during spring and summer. The frequency of strong westerly winds increases during winter months (July to August). Winter also witnesses an increased amount of wind from the west-north-west.

Table 2-23 is a summary of highest wind speeds recorded at Thyspunt for the period January 2008 to September 2009. The site experienced exceptionally strong winds in May 2009 (highest gust of 31.6 m/s).

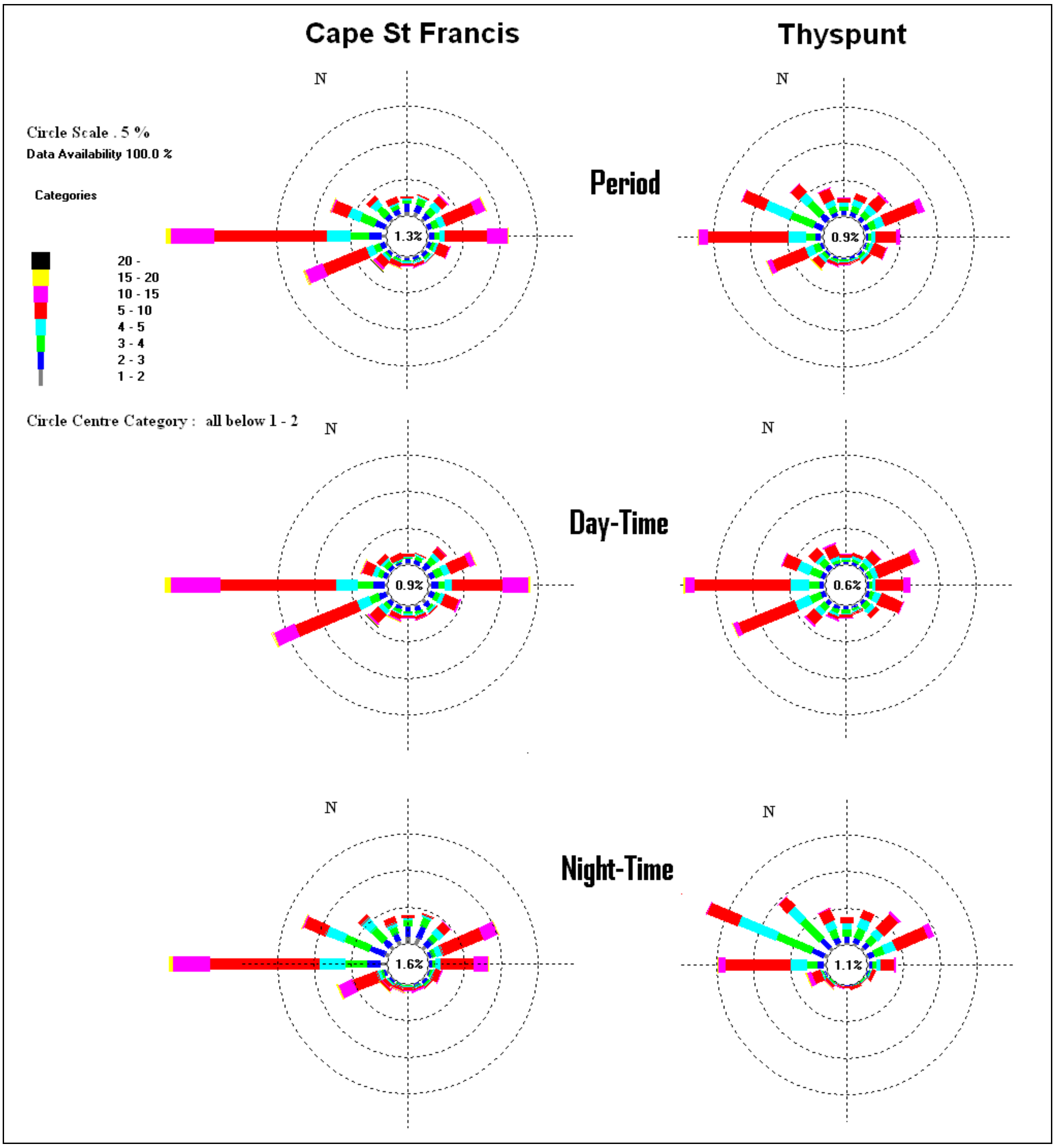


Figure 2-25: Comparison of wind roses between Cape St. Francis (SAWS, 2004 to 2008) and onsite, Thyspunt (January 2008 to September 2009) data

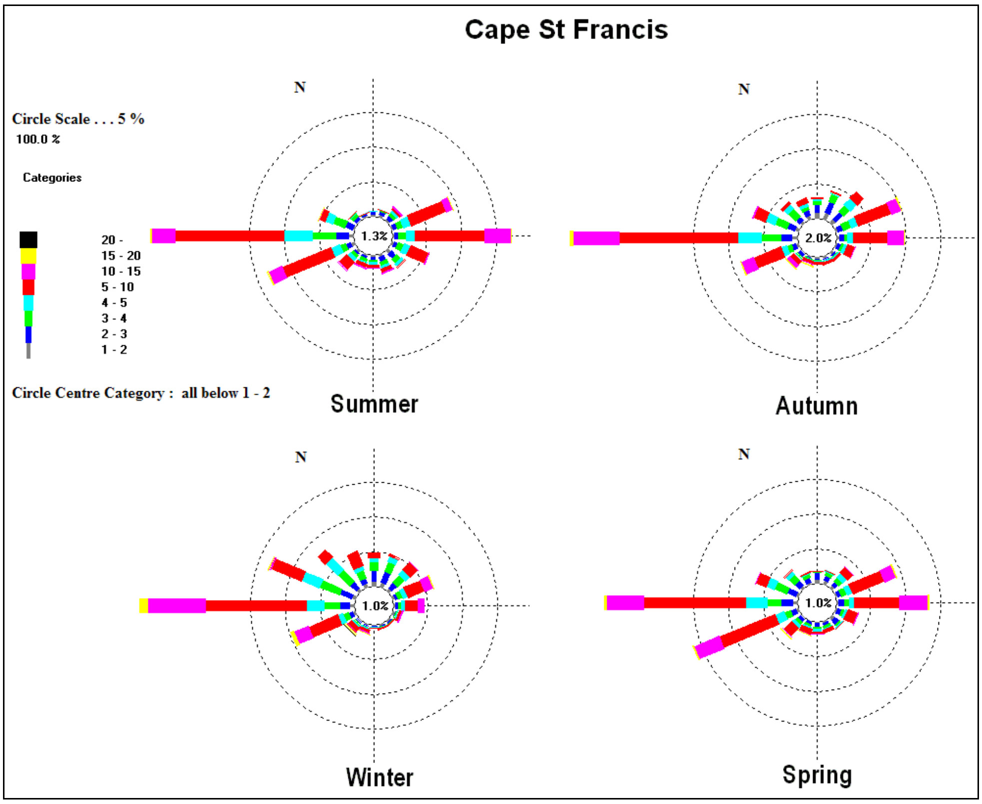


Figure 2-26: Seasonal wind roses for Cape St. Francis (SAWS, 2004 to 2007)

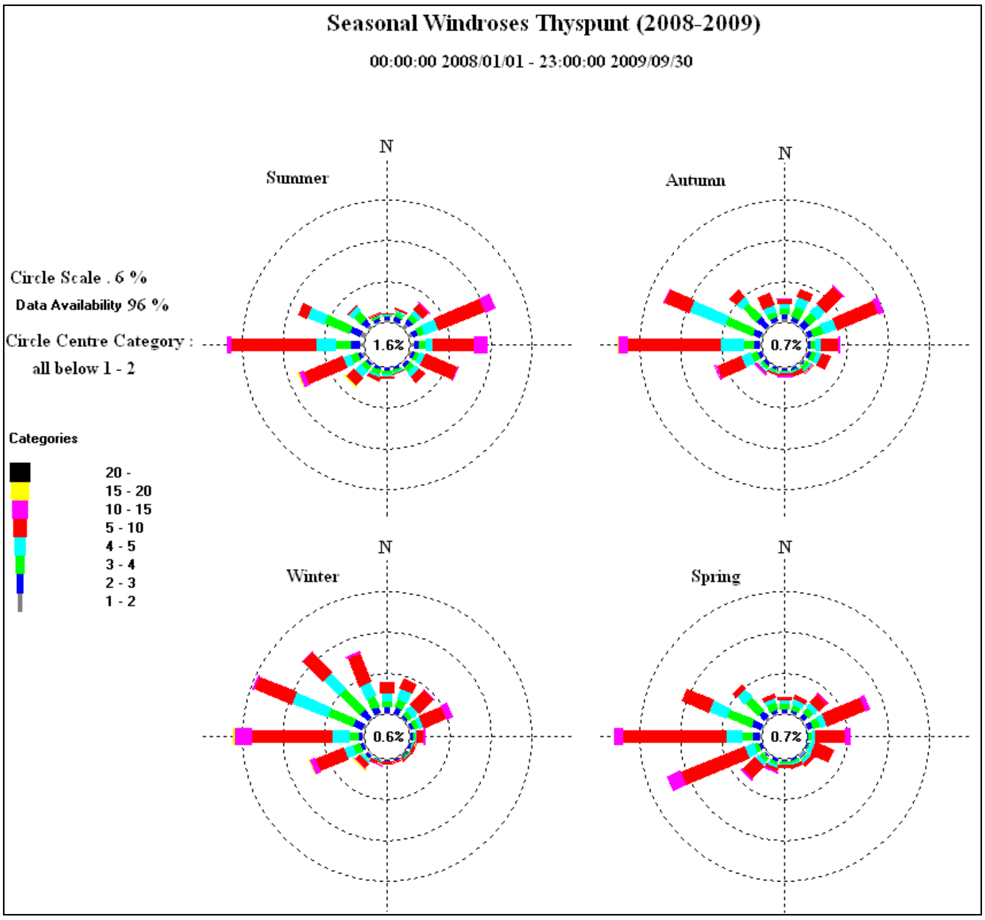


Figure 2-27: Seasonal wind roses for Thyspunt (January 2008 to September 2009)

Table 2-23: Highest wind gusts measured at Thyspunt (January 2008 to September 2009)

Month	Wind Gust (m/s)	Wind Bearing
January	19.04	E
February	20.19	ENE
March	21.85	W
April	20.83	W
May	31.63	W
June	28.44	W
July	24.63	WSW
August	27.55	WSW
September	22.1	W
October	30.4	W
November	17.94	W
December	24.15	WSW

(ii) Atmospheric Stability

Atmospheric stability was calculated according to the "Sigma Theta" method. (The "Delta-T" method, which was the additional method used to estimate stability at the Duynefontein site, requires two temperature readings at different vertical heights on a tall mast. This information is not currently available on the 10 m mast at the site).On an annual basis, the highest frequency of stability class occurrence is neutral (68.2%) followed by slightly stable 11.6%. The mean wind speeds with these two stability classes are 5.9 m/s and 5.7 m/s, respectively. Extremely unstable conditions occur 3.1% of the time with a mean wind speed of 2.9 m/s, while extremely stable conditions occur only 1.8% of the time with a mean wind speed of 2.4 m/s.

(iii) Ambient Air Temperature

The recorded dry-bulb temperatures at Thyspunt for the period January 2008 to September 2009 are summarised in Table 2-24. The highest maximum temperature (36.6°C) was recorded during March 2008 with the lowest (7.6°C) during September 2009.

Table 2-24: Dry-bulb temperature observations at Thyspunt (January 2008 to September 2009)

Month	Daily Average (°C)	Daily Maximum (°C)	Daily Minimum (°C)
January	20.1	29.4	14.8
February	20.3	30.9	14.7
March	19.8	36.6	11.7
April	17.9	31.3	10.7
May	17.3	31.8	8.4
June	15.1	26.3	7.8
July	14.7	28.8	7.9
August	14.9	31.3	7.9
September	14.7	35.5	7.6
October	16.3	26.0	9.4
November	17.2	28.1	11.7
December	19.3	27.9	11.8

The ambient air temperature statistics for Cape St. Francis are summarised in Table 2-25. The tables contain the average daily maximums, minimums and extreme maximums and minimums. The average daily maximum and minimum temperature recorded at Cape St. Francis were 22.8°C (January and February) and 11.2°C (July), respectively. The extreme maximum and minimum were 36.5°C (May) and 5.0°C (August), respectively.

Table 2-25: Means and extremes of temperature for Cape St. Francis for the period 2004 (June) to 2007

Month	Average Daily Maximum (°C)	Extreme Maximum (°C)	Average Daily Minimum (°C)	Extreme minimum (°C)
January	22.8	27.4	18.5	12.9
February	22.8	28.3	18.4	14.1
March	21.8	25.5	16.7	12.9
April	19.6	25.3	14.7	9.1
May	19.4	36.5	13.3	7.1
June	18.8	29.0	11.7	6.8
July	18.1	28.0	11.2	6.6
August	17.9	30.5	11.6	5.0
September	18.1	24.4	12.9	7.0
October	19.2	25.5	14.2	8.5
November	20.9	31.1	15.9	11.2
December	22.0	25.0	17.4	12.6
Annual	20.1	36.5	14.7	5.0

(iv) Solar Radiation

Solar radiation measurements for Thyspunt are available for January 2008 to September 2009. A comparison of these observations to the estimates made by Schulze (1997) is made in Table 2-26. The observations during the winter period are shown to be slightly lower than the estimates by Schulze (1997).

Table 2-26: Solar Radiation ($MJ.m^{-2}.day^{-1}$) for Thyspunt

Month	Observed (2008/2009)	Estimate (Schulz 1997)		
		Mean	Maximum	Minimum
January	21.3	31.4	38.1	21.0
February	20.9	28.5	34.1	19.9
March	19.8	24.0	27.4	18.0
April	14.5	19.7	22.3	15.8
May	11.6	15.6	18.1	12.5
June	9.0	13.4	15.7	11.2
July	8.8	14.4	17.0	12.0
August	13.6	18.2	21.7	14.4
September	17.5	23.0	27.2	16.6
October	21.1	27.3	32.5	19.0
November	22.0	30.2	36.6	20.5
December	26.0	32.2	38.9	21.5

(v) Atmospheric Moisture

Relative humidity has been recorded since January 2008. Table 2-27 is a summary of the measurements for the period January 2008 to September 2009. The average relative humidity appears to be the same as at Bantamsklip, i.e. around 78% with the lowest recording during August, i.e. 9.9 %.

Table 2-27: Relative humidity measurements at Thyspunt (January 2008 to September 2009)

Month	Daily Average (%)	Daily Minimum (%)	Daily Maximum (%)
January	85.1	51.2	99.9
February	82.9	38.9	99.9
March	81.9	14.0	100.0
April	79.5	13.4	100.0
May	74.1	17.1	98.8
June	72.5	24.5	97.3
July	71.0	12.5	99.9
August	78.9	9.9	99.9
September	80.9	12.0	100.0
October	80.9	38.3	100.0
November	85.1	53.0	100.0
December	81.9	43.7	99.9

(vi) Precipitation

The rainfall season for the Thyspunt area is classified as all year round and is also seen in the solar radiation values being lower in summer and winter than the surrounding areas (Figure 2-20). The mean annual precipitation is expected to be between 600 mm and 800 mm, as shown in Figure 2-21. The rainfall observations made at the SAWS station in Cape St. Francis recorded an annual average of 610.9 mm for the period 2004 (June) to 2007 (Table 2-28). Ignoring 2004, the mean annual average rainfall is 587.9 mm (i.e. 2005: 456.4 mm; 2006: 538.2 mm; 2006: 769.0 mm).

Table 2-28: Average, maximum and minimum monthly rainfall (mm) for Cape St. Francis for the period 2004 (June) to 2007

Month	Average Monthly	Maximum Monthly	Minimum Monthly
January	32.2	46.4	18.6
February	18.4	33.8	8.6
March	80.6	173.4	12
April	61.2	71.8	41.6
May	61.6	106.8	18.4
June	33.9	51	19.2
July	40.4	80.4	6.6
August	101.1	211.4	26.8
September	32.8	69	17
October	43.0	64	17.4
November	44.6	94.2	12.4
December	61.3	138	15.4
Total	610.9		
Mean Annual Average	587.9		

Rainfall measurements at Thyspunt commenced in January 2008. The monthly totals and the highest 24-hourly rates are given in Table 2-29. The total rainfall at Thyspunt for 2008 is 516.4 mm, which is similar to the mean annual average of 587.9 mm at Cape St Francis.

Table 2-29: Monthly precipitation recorded at Thyspunt from January 2008 to September 2009

Month	Month Total (mm)	Highest 24-Hourly (mm)
January	19.2	7.2
February	48.0	12.9
March	21.8	3.6
April	83.1	42.4
May	23.5	4.5
June	98.4	10.6
July	31.4	8.9
August	44.9	9.3
September	17.1	5.2
October	81.6	32.5
November	121.6	12.3
December	6.5	1.8

(vii) Thunder and Hail

Table 2-30 is a summary of the monthly average number of days that thunder and hail occurred based on the climate data for Cape St. Francis. It would appear that Thyspunt experiences more thunder days than at Bantamsklip, but similar to Cape Town.

Table 2-30: Average monthly and annual number of days with thunder, hail, snow and fog for Cape St. Francis (1881-1984) (South African Weather Service)

Month	Thunder	Hail
Jan	0.6	0.0
Feb	0.7	0.0
Mar	1.0	0.0
Apr	0.8	0.0
May	0.7	0.2
Jun	0.3	0.1
Jul	0.3	0.2
Aug	0.4	0.2
Sep	0.5	0.0
Oct	0.8	0.1
Nov	0.6	0.0
Dec	0.5	0.0
Annual	7.2	0.8

(viii) Snow and Frost

Table 2-31 is a summary of the monthly average number of days that snow occurred based on the climate data for Cape St. Francis. No frost data could be obtained.

Table 2-31: Average monthly and annual number of days with frost and snow for Cape St. Francis (1881-1984) (South African Weather Service)

Month	Frost	Snow
Jan	No Data	0.0
Feb	No Data	0.0
Mar	No Data	0.0
Apr	No Data	0.0
May	No Data	0.0
Jun	No Data	0.0
Jul	No Data	0.0
Aug	No Data	0.0
Sep	No Data	0.0
Oct	No Data	0.0
Nov	No Data	0.0
Dec	No Data	0.0
Annual	No Data	0.0

(ix) Fog

Table 2-32 is a summary of the monthly average number of days that fog occurred based on the climate data for Cape St. Francis.

Table 2-32: Average monthly and annual number of days with fog for Cape St. Francis (1881-1984) (South African Weather Service)

Month	Fog
Jan	2.0
Feb	4.0
Mar	4.8
Apr	2.8
May	1.1
Jun	0.2
Jul	0.5
Aug	0.8
Sep	1.0
Oct	2.4
Nov	2.1
Dec	2.6
Annual	24.3

(x) Evaporation

The Penman-Monteith method was employed to calculate evaporation rates for the monitoring period January 2008 to September 2009 and summarised Table 2-33.

2.3.4 Severe Weather Phenomena

The meteorological variables whose extreme values are to be evaluated are those associated with wind, precipitation and ambient air temperatures. The following discussion is a summary of these parameters for each of the three sites.

Table 2-33: Monthly evaporation rate calculated for Thyspunt for January 2008 to September 2009

Month	Month Total (mm)
January	111.8
February	107.1
March	113.0
April	84.7
May	79.0
June	63.6
July	60.8
August	78.1
September	87.4
October	108.5
November	106.4
December	138.3

The south-western and southern coasts are subjected to large synoptic scale systems that drive the local weather conditions at any given area. As is described in the South African Weather Bureau's WB40 Report (Schulze 1986), these local weather conditions are normally characterised as low level stratus clouds and not by towering convective storms that produce hail and thunder showers. Severe weather is more closely associated with severe wind conditions. Goliger and Retief (2007) identified four main wind producing systems namely:

- Coastal low buster;
- Cut-off lows;
- Shallow south-easterlies; and
- Mid-latitude lows.

The last two systems are the most significant in terms of wind speed. Winds in these systems can produce speeds at ground level of up to 35 m/s (126 km/h), which can cause considerable damage to buildings that are not designed to withstand these conditions.

Tornadoes are amongst the most violent and destructive of all weather phenomena. A tornado is a violent rotating column of air extending from a thunderstorm. Tornadoes in South Africa are typically associated with very hot air masses and severe thunderstorms. To date scientists do not know exactly how tornadoes are formed, but all the evidence suggests that they develop as a combination of (1) strong spinning effects inside a thunderstorm or in the air surrounding the storm and (2) accelerated strong updrafts (wind moving vertically in an upward direction). There are several different methods of classifying tornadoes. The most commonly used is the "Fujita-Pearson scale classification". This system classifies tornadoes in six intensities, ranging from F0 (no damage) to F5 (incredible damage). The intensity is based on the apparent damage to structures, the extent of the path and other descriptors from which wind speeds are then inferred. Sixty five percent of the South African tornadoes are classified as F0 or F1 (light damage), while more than 90% are classified as F0, F1 or F2 (considerable damage) or less.

Based on an analysis of the occurrence of South African tornadoes for the period 1905 to 1997 by SAWS, most tornadoes have been observed in Gauteng, the Free State, KwaZulu-Natal (along a line from Pietermaritzburg to Ladysmith) and the northern region of the former Transkei. Furthermore, most of these events occur in mid-summer from November to January, although a large number of tornadoes have occurred in spring and early summer (September and October) and in the late summer and autumn (February to May). An analysis of tornado time of occurrence revealed that most events occurred in the late afternoon or early evening, typically between 16:00 and 19:00.

The Western and Eastern Cape provinces are not located on a hurricane track or adjacent to a warm ocean. None of the three alternative sites are therefore likely to experience a hurricane. Similarly, these sites are not subject to tropical cyclones as these occur on the north-eastern coast of South Africa.

There is, however, a difference between a hurricane and hurricane force winds that should be noted. The latter refers to a wind speed scale called the Beaufort Scale where hurricane force winds are those with speeds above 118 km/h. Storm force wind occur relatively frequently at all three sites.

(a) Duynefontein

Tornadoes can occur basically anywhere where a thunderstorm is possible. Although tornadoes are not common in the Western Cape, recent evidence of a relatively weak tornado occurred on the 2nd October 2002 in the Cape Peninsula. A frontal trough of low pressure approached the Cape during the evening and made landfall at approximately 20h00. The swirling winds ripped away parts of the asbestos roofs of two blocks of flats, while a third block of flats had its roof slightly lifted in Pecos Road, Mannenberg, Fourteen other roofs in Vygekraal, Rio Grande and Renoster Roads were also lifted, with fifty more homes sustaining minor damage. Altogether 81 people were displaced by the event. Inspection of the upwind area showed a tree that had been partially flattened by the wind. One heavy branch of this tree had been moved approximately 15 metres. Patterns of the flattened grass in this area showed considerable shearing action, which is consistent with tornado action. Taking into considering the pattern of the damage caused on 2 October 2002, it would appear that this occurrence was indeed a tornado. However the extent and area coverage was such that it can only be classified as intensity F0 on the Fujita Pearson scale, which is a weak tornado.

Although the Western Cape is not on a hurricane track, hurricane force winds have frequently occurred in the area. The latter refers to a wind speed scale called the Beaufort Scale. Such a storm occurred in 2003. On 18 and 19 August 2003, a series of intense frontal vortices affected the South-Western Cape. The passage of the initial cold front at approximately 2 pm on Monday was associated with average winds of over 93 km/hr (25.7 m/s) in Table Bay, gusting to over 130 km/hr (36 m/s) at times. On the Beaufort wind scale this translates to Force 10 – i.e. 'Storm Force' winds. These winds resulted in considerable damage in parts of the Greater Cape Town area. The casualty with the highest profile was without doubt the container vessel 'Sealand Express', which ran aground at 06:30 on 19 August. In actual fact the winds had dropped considerably by this time but unusually strong currents may well have been present in Table Bay as a result of the heavy swell.

This force classification threshold is often exceeded at the Duynefontein site, as proven by data collected at the Koeberg meteorological weather station. The site experienced exceptionally strong winds (tornadoes/waterspouts) in May 1987, with highest gusts of up to 38.3 m/s. The highest mean hourly velocity (HMHV) recorded at the Cape Town Weather Office was 144 km/h with the highest gust of 245 km/h SAWS 1996. The HMHV and wind gust recorded at Cape Town International Airport (1956 – 1973) are 87.5 km/h (24.3 m/s) and 141.5 km/h (39.3) m/s, respectively (Le Roux, 1983).

Cape Town International Airport only experiences on average 7.3 days of thunder and 0.9 days of hail. According to SAWS, the region experiences 1 or less flash per year per km². This generally implies relatively low precipitation rates, but a long duration of precipitation.

Historical records (Le Roux, 1983) of ambient dry bulb air temperature recorded at Cape Town International Airport report an extreme maximum temperature of 40.7°C (1956-1973) and an extreme minimum temperature of -1.3°C. This weather station is located inland and therefore not as much influenced by the close proximity of the cold ocean current as Duynefontein. The ocean current has a moderating effect on the temperatures: the lowest dry-bulb temperature recorded at Duynefontein site is above freezing (2.2°C on 2 August 1981) and the maximum is 38.2°C (13 September 2005).

Rainfall records of observations at Cape Town International Airport for the period 1938 to 1972 (Le Roux, 1983) conclude a maximum rainfall rate of 61.7 mm for a 24-hour period, measured from midnight to midnight, The highest rainfall rate recorded for 15-, 30-, 45- and 60-minute periods are 16 mm, 28.8 mm, 36.3 and 39.1 mm, respectively. In comparison, the maximum amount of rainfall recorded at Duynefontein in a 24-hour period is 58.2 mm, measured on the 14 June 1996.

(b) Bantamsklip

The SAWS records for 2001 to 2007 reported the highest hourly average wind speeds at Hermanus and Struisbaai to be 16 m/s (57.6 km/h) at Hermanus and 17.8 m/s (64.1 km/h) at Struisbaai. The maximum instantaneous wind gusts recorded at Hermanus for the period 1992 to 2002 was 32.2 m/s, and at Struisbaai (1991 to 2002), 34.4 m/s (Kruger 2002).

The highest hourly average wind speed measured at Bantamsklip was 15.9 m/s (57.2 km/h) on 9 February 2008. Gusts of up to 21.6 m/s were recorded during that period. Gale-force winds and heavy rain caused widespread destruction in several parts of the Western Cape over the weekend of the 30th and 31st August 2008. The highest hourly average wind speed measured on these days at Bantamsklip was 14.3 m/s (51.5 km/h). Gusts of up to 24.9 m/s (89.6 km/h, “Force 10” on Beaufort-Scale) were recorded.

As for Duynefontein site, this location is not on a hurricane track or adjacent to a warm ocean. The Bantamsklip site will therefore not experience a hurricane. Similarly, the Bantamsklip site is not subject to tropical cyclones as these occur on the northeast coast of South Africa.

Danger Point only experiences on average 13.5 days of thunder and 3.3 days of hail per year. According to SAWS, the region experiences 1 or less flash per year per km². This generally implies relatively low precipitation rates, but a long duration of precipitation.

(c) Thyspunt

The highest wind speed recorded by SAWS at Cape St. Francis for the period from June 2004 to December 2007 was 20 m/s (72 km/h). Although further located, the highest hourly average wind speed and gust recorded over the period 1943 to 1973 at Port Elizabeth (approximately 90 km east-northeast of Thyspunt) were 75.6 km/h and 138.2 km/h, respectively (Le Roux, 1989).

The highest hourly average wind speed occurred on 23 July 2009, with 18.2 m/s (65.5 km/hr) and gusts of 24.5 m/s (88.2 km/hr). Intense weather was recorded at Thyspunt over the weekend of the 30th and 31st August 2008. The highest hourly average wind speed on these days was 16.4 m/s (59 km/h) with gusts of up to 26.2 m/s (94.5 km/h, “Force 10” on Beaufort-Scale).

Thyspunt will not experience a hurricane since it is not on a hurricane track or adjacent to a warm ocean. The Thyspunt site is also not subject to tropical cyclones.

According to SAWS, the region experiences two or less lightning flashes per year per km^2. Cape St. Francis only experience on average 7.2 days of thunder and 0.8 days of hail.

2.3.5 Potential Climatological Effects of Global Warming

Perhaps the most important finding of the Assessment Reports of the Inter-Governmental Panel for Climate Change (IPCC) is that the average of global lower atmospheric temperatures observed since the 1860s had risen by ±0.7˚C. These reports also made projections that these temperatures might even increase in future. The Fourth Assessment report (Solomon *et al*., 2007) came to the important conclusion that there is a 90% probability that the rising temperature, as indicated in the previous IPCC reports, can be attributed to anthropogenic (human induced) activities. The focus of this section will be the impact of these findings on the southern Africa region, and in particular the Western Cape and southern coastline of South Africa. Most research in our region has focussed on changes in temperature and rainfall. The City of Cape Town has recently commissioned a study on sea-level rise risks. The aim of the *Sea-Level Rise Risk Assessment* is to predict the ramifications of sea-level changes as a result of climate change on existing coastal systems (*personal communication Gregg Oelofse, City of Cape Town*). A considerable amount of work still needs to be done on the impact of global warming on regional weather patterns and the associated climate, which again regulate wind propagation and wind related storms.

Atmospheric general circulation models (GCMs), and in particular climate models, are the only aid available to generate future climate projections. These models use the laws of Newton to describe flow patterns in the atmosphere, but since these atmospheric equations can not be completely solved, numerical estimations are made. Furthermore, these estimations might differ between models. As a result some scientists criticise the use of numerical models, arguing that these simulations are subjected to uncertainties because of the chaotic nature of the atmosphere and because of numerical estimations and the parameterisation of physical atmospheric processes. Information about climate and how it responds to increased greenhouse gas concentrations depends heavily on insight gained from numerical simulations by coupled climate models. The confidence placed in quantitative estimates of the rate and magnitude of future climate change is therefore strongly related to the quality of these models. By validating against observations of present climate, it has been shown that the coupled models have been steadily improving over time and that the best models are converging toward a level of accuracy that is similar to observation-based analyses of the atmosphere (Reichler and Kim, 2008). Since other means to generate future climate scenarios do not exist (apart from stochastic analyses that have limitations), it is assumed that despite all their shortcomings, modern climate models are the only aids capable of providing valuable answers on what might be expected under future conditions of increased greenhouse gas emissions. These conditions are more than 90% likely to be attributed to anthropogenic activities (IPCC, 2007).

Under the World Climate Research Programme (WCRP) the Working Group on Coupled Modelling (WGCM) established the Coupled Model Inter-comparison Project (CMIP) as a standard experimental protocol for studying the output of coupled atmosphere-ocean general circulation models (AOGCMs). CMIP provides a community-based infrastructure in support of climate model diagnosis, validation, inter-comparison, documentation and data access. This framework enables a diverse community of scientists to analyse GCMs in a systematic fashion, a process which serves to facilitate model improvement. Virtually the entire international climate modelling community has participated in this project since its inception in 1995. The Program for Climate Model Diagnosis and Inter-comparison (PCMDI) archives much of the CMIP data and provides other support for CMIP. AOGCMs allow the simulated climate to adjust to changes in climate forcing, such as increasing atmospheric carbon dioxide.

CMIP began in 1995 by collecting output from model "control runs" in which climate forcing is held constant. Later versions of CMIP have collected output from an idealised scenario of global warming, with atmospheric carbon dioxide increasing at the rate of 1% per year until it doubles at about Year 70. Phase three of CMIP (CMIP3) included "realistic" scenarios for both past and present climate forcing. The research based on this dataset provided much of the new material underlying the IPCC Forth Assessment Report (Solomon *et al*., 2007).

The IPCC published a new set of scenarios in 2000 for use in the Third Assessment Report (Special Report on Emissions Scenarios - SRES). The SRES scenarios were constructed to explore future developments in the global environment with special reference to the production of greenhouse gases and aerosol precursor emissions. The SRES team defined four narrative storylines, labelled A1, A2, B1 and B2, describing the relationships between the forces driving greenhouse gas and aerosol emissions and their evolution during the 21st century for large world regions and globally. Each storyline represents different demographic, social, economic, technological, and environmental developments that diverge in increasingly irreversible ways. In simple terms, the four storylines combine two sets of divergent tendencies: one set varying between strong economic values and strong environmental values, the other set between increasing globalisation and increasing regionalisation. The storylines are summarised as follows (Nakicenovic *et al.,* 2000):

- A1 storyline and scenario family: a future world of very rapid economic growth, global population that peaks in mid-century and declines thereafter, and rapid introduction of new and more efficient technologies.
- A2 storyline and scenario family: a very heterogeneous world with continuously increasing global population and regionally oriented economic growth that is more fragmented and slower than in other storylines.
- B1 storyline and scenario family: a convergent world with the same global population as in the A1 storyline but with rapid changes in economic structures toward a service and information economy, with reductions in material intensity, and the introduction of clean and resource-efficient technologies.
- B2 storyline and scenario family: a world in which the emphasis is on local solutions to economic, social, and environmental sustainability, with continuously increasing population (lower than A2) and intermediate economic development.

(a) Southern Africa Temperature and Rainfall

In an attempt to further reduce the degree of uncertainty, it is recommended that an ensemble of outputs from more than one model is used. Thus, in the most recent Fourth Assessment Report of the IPCC (Solomon *et al.*, 2007), 21 of the most advanced international climate models were employed in a study to estimate what changes might occur in absolute near-surface temperature and percentage rainfall over southern Africa (Figure 2-28), relative to the present climate (1979-1998) under conditions of a doubling of greenhouse gases in the 2090s (2079-2098).

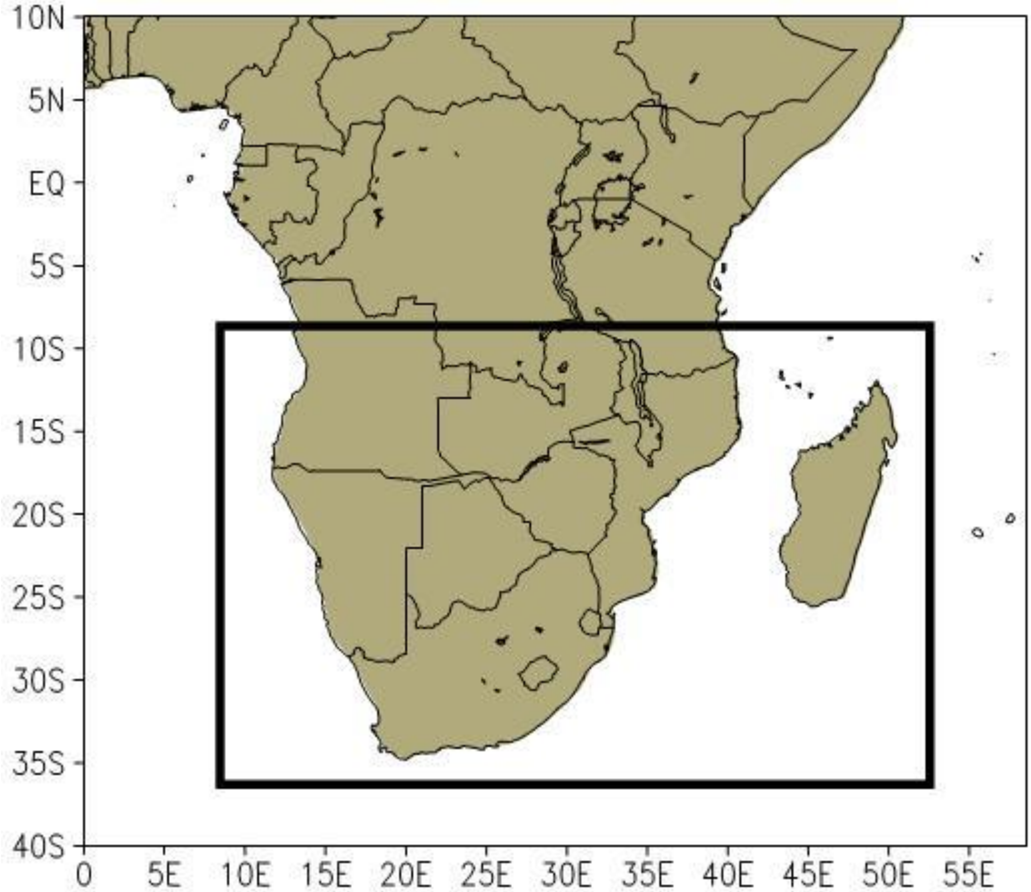


Figure 2-28: Southern Africa region selected to calculate rainfall percentage and absolute temperature changes under conditions of greenhouse warming

Results in the following figures represent averages in the domain drawn over southern Africa.

The IPCC 4th Assessment Report indicates projected changes in annual absolute temperature and percentage rainfall for the period 2079-2089, averaged over the southern Africa domain (Figure 2-29). The A1B greenhouse gas emission scenario (an approximated doubling in CO_2 concentrations in 2100) was considered, implying an approximated doubling of greenhouse gasses over the next 100 years. The cross (+) represents the average projection by all these models. For absolute temperature, results are grouped at a projected change of approximately +3.2˚C, indicating that all models agrees that temperatures over southern Africa might rise (positive deviation) in future. According to Figure 2-29, percentage rainfall deviations do not show large positive or negative anomalies, but are rather grouped around the zero line. This suggests that annual rainfall totals are not expected to rise or fall significantly. It should be noted that rainfall intensities may, however, differ. Despite stochastic efforts to draw regional conclusions from IPCC model data, the climate model findings illustrated in Figure 2-29 are still regarded as the best available.

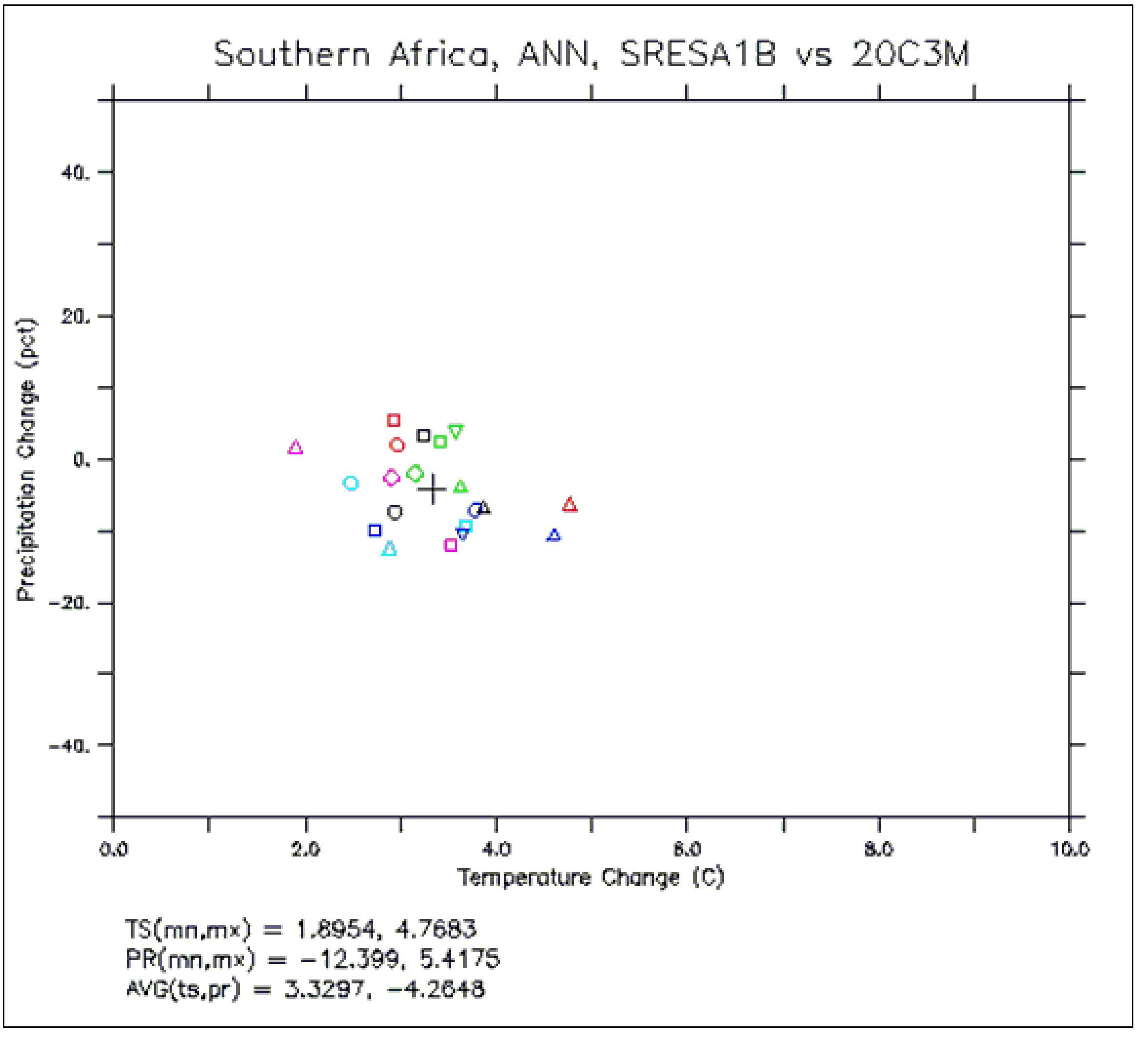


Figure 2-29: Absolute temperature and percentage rainfall changes in ANNUAL rainfall totals, (2079-2098) minus (1979-1998) (4th Assessment Reports of the IPCC (Solomon *et al.*, 2007))

Figure 2-30 illustrates projected changes over the mid-summer season (December-January-February, or DJF). This is very similar to Figure 2-29, which gave annual projected changes. This implies that although a rise in absolute temperatures might be expected, annual and mid-summer rainfall totals might not change much in future. Take note that the summer rainfall region extends over the central and entire eastern part of southern Africa, with a gradual increase in rainfall from west to east. Although these predictions indicate that severe deviations in rainfall might not be expected, intra-annual changes (shift of season and the length of seasons) with more evaporation as a result of increased temperatures are still realities to take note of. Over the summer rainfall region of southern Africa water resource management is therefore a higher priority than preparing for significantly wetter or dryer conditions.

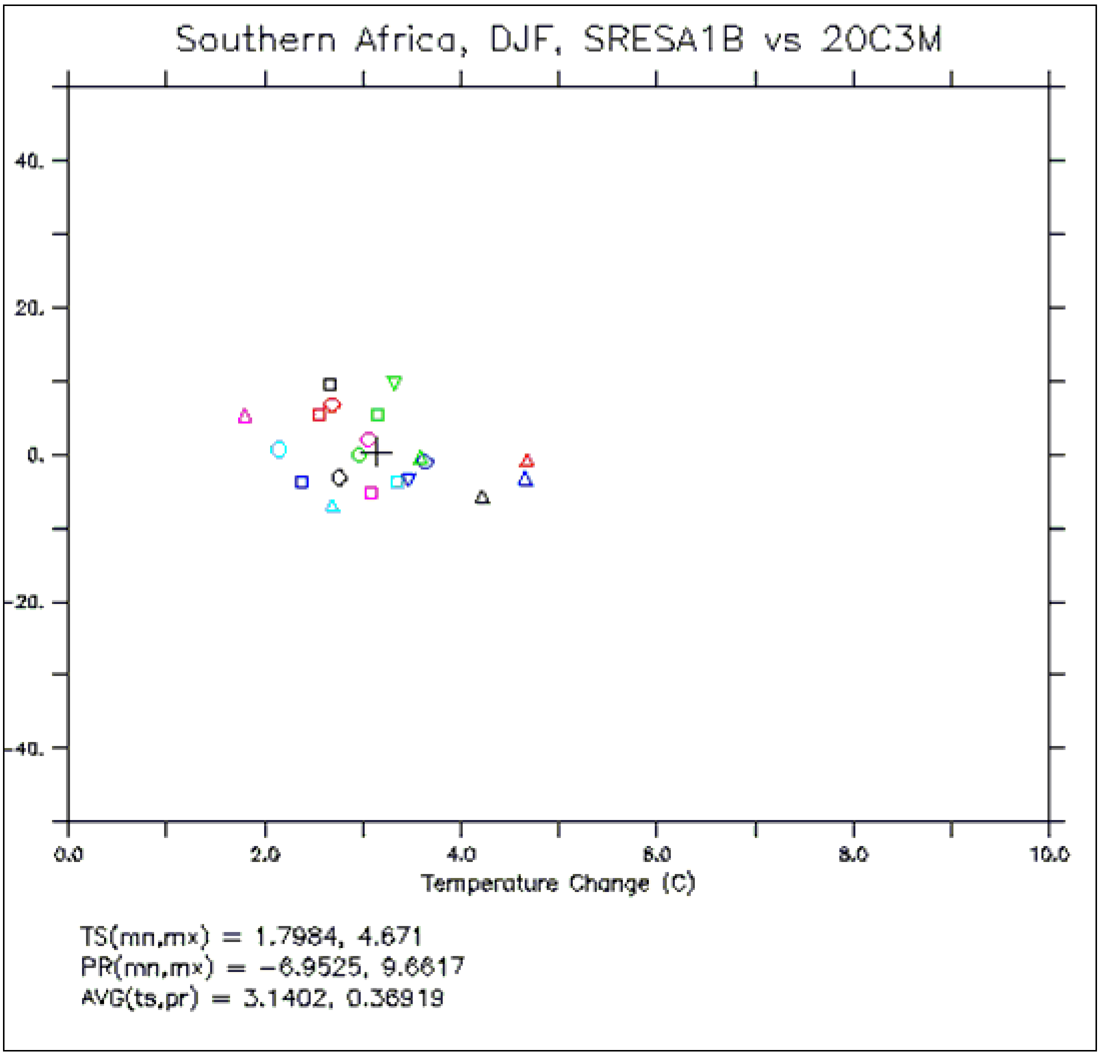


Figure 2-30: As for Figure 2-29, but for the mid-summer season (December-January-February)

Mid-winter (June-July-August or JJA) projections differ from those of annual and mid-summer projections, since all 21 models project below present-day rainfall in 2079-2098. The winter rainfall region of southern Africa is confined to the Western Cape and southern coastline of Africa, which is also the area under investigation in this report. Figure 2-31 implies that there is a risk that rainfall over the Western Cape might decrease in future under conditions of greenhouse warming.

The IPCC models all agree that temperatures might increase in future, although projected changes in rainfall is more variable. The spatial distribution of projected percentage rainfall changes in approximately 100 years from now (2080-2099) are illustrated in Figure 2-32. The western coastline and its adjacent interior is the area where the largest negative anomalies are projected. One must, however, keep in mind that the west coast receives less rain than areas over the summer rainfall region. This implies that larger percentage changes in rainfall might imply smaller rainfall total change over the west coast in comparison to the summer rainfall region – especially if compared to annual rainfall totals. Despite this, the west coast is still the region most at risk.

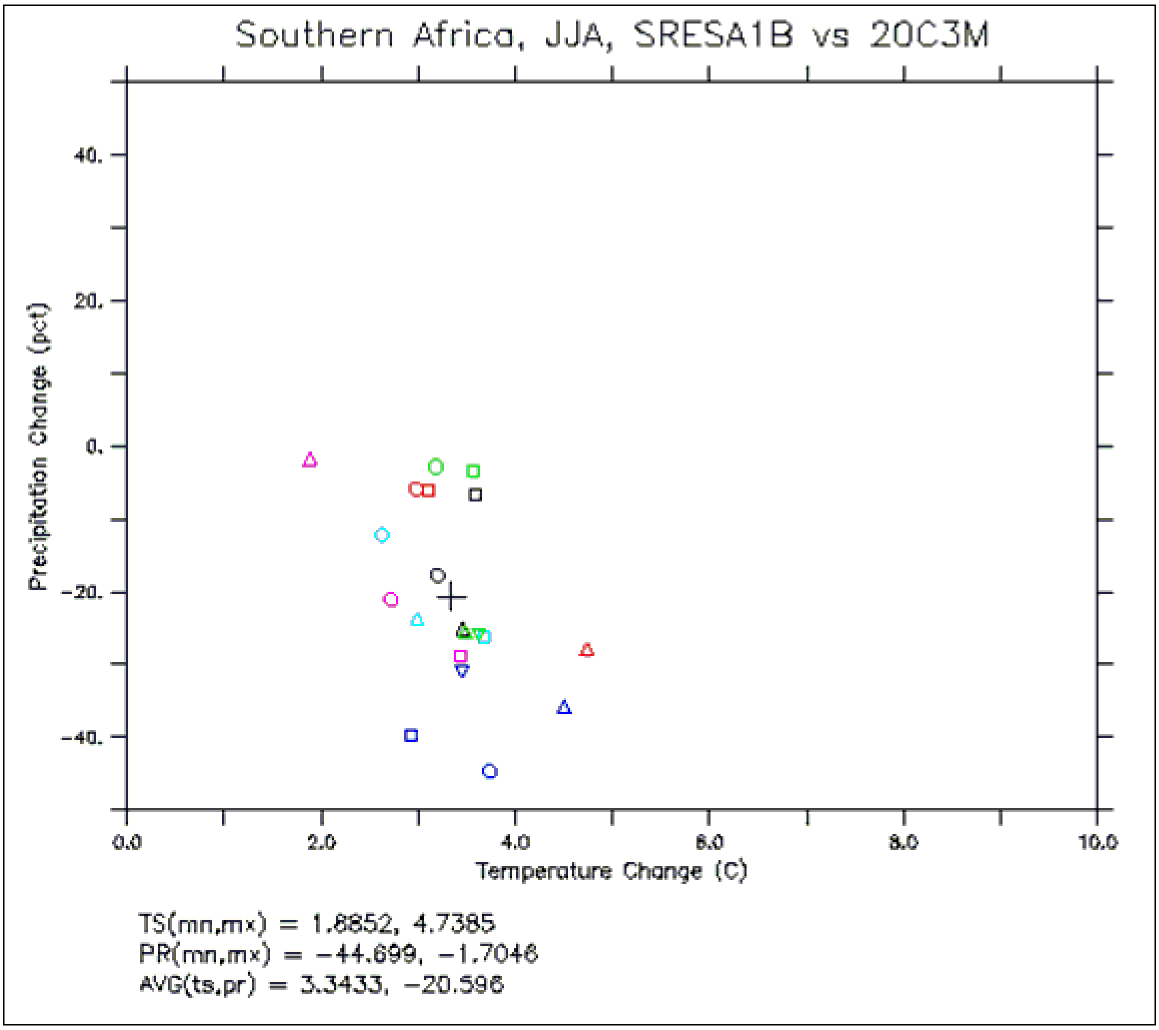


Figure 2-31: Same as Figure 2-30, but for the winter season June-July-August

The most recent IPCC results indicate that large changes in annual and mid-summer rainfall totals over southern Africa are unlikely to occur. This is supported by trend analyses of observed annual rainfall totals, where no statistically significant spatially coherent trends could be found over the past 40 years (Rautenbach and Mphepya, 2005). Trend analyses, however, suggest that shift in seasons might have occurred, with a consistent negative trend detected during April (and to a lesser extend during May) over the summer rainfall region. Also, positive rainfall trends were noticed over the western parts of South Africa during the months July and September. These findings might suggest that the summer rainfall season is getting shorter, whilst the winter rainfall season might get longer. One might argue that if annual rainfall totals do not change much, and more rain occurs over a shorter period over the summer rainfall region (with an increasing longer dry winter), more extreme rainfall events might be expected. The same argument applies for winter rain, which appear to become more spread out over time: this result in already drier conditions in observations. These findings are preliminary, but indicate that despite small changes in annual rainfall, South Africa may need to prepare for more extreme rainfall events in future, with longer dry periods in between.

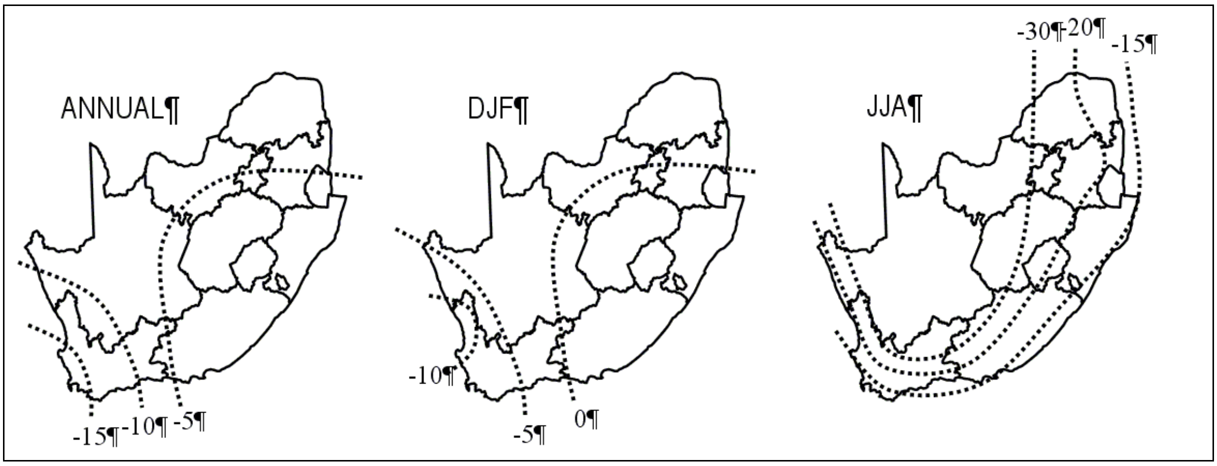


Figure 2-32: Percentage rainfall changes over South Africa for the annual (left), summer (middle) and winter (right) periods. Differences are between 1980 to 1999 (present) and 2080 to 2099 (Solomon *et al.*, 2007)

In summary, the three sites are all located along the southern and western coastline of South Africa. From the above discussion, there is evidence that the two western sites (Duynefontein and Bantamsklip) might experience increased dry conditions in future, with a probable increase in the frequency of stormy weather. This might lead to occasional rough seas and higher swells. The results indicate that for Thyspunt large changes in annual and mid-summer rainfall totals are unlikely to occur.

(b) Synoptic Patterns and Winds

Very little is currently known about the impact that greenhouse warming might have in future on changes in regional scale synoptic weather and climate patterns over southern Africa. Despite this lack of knowledge, one can draw some conclusions by only considering projected temperature changes.

Winds and synoptic patterns over the Western Cape and southern coastline of Africa are mostly influenced by zonal temperature (and pressure) gradients as a result of a warmer continent and colder adjacent ocean, as well as by west-to-east propagating mid-latitude cyclones (cold fronts). These cyclones develop as a result of cold polar air that propagates northwards to exchange energy with warmer tropical air – a process attributed to energy (heat) differences between polar and equatorial regions and the Earth system's effort to balance these differences. Recent studies and climate change projections indicate that global warming might affect temperatures in the Northern Hemisphere significantly more than in the Southern Hemisphere, and that equatorial regions might warm faster than higher latitude regions. This implies that the South Pole might warm slower than regions to the north. Stronger temperature gradients accompanied by stronger winds over the mid-latitudes of the Southern Hemisphere might therefore become more likely. Northward propagating polar air, in the form of cold fronts, might lead to strong winds and storms if the continental atmosphere over South Africa warms up as projected.

It should be noted that over the recent two years steep pressure (temperature) gradients resulted in extreme weather conditions along the southern coast line of South Africa, and the likelihood that related storms will increase in frequency under conditions of global warming is high. If such storms coincide with high tides or rising sea levels, structural damage might increase.

During construction of the nuclear power station special precautionary measures should be implemented to reduce the danger of damage by stormy weather. If practically possible it is recommended that barriers should be placed to break the impact of high swells at a distance from the coastline.

(c) Summary

Table 2-34 provides a summary of the main meteorological parameter changes projected for the next century. Temperatures across South Africa have increased in the historical past, and are projected to increase into the future throughout the 21st century. Future warming might be greatest in the interior of the country and less along the coast. Assuming a moderate to high growth in greenhouse gas concentrations (SRES A2 scenario), by mid-century the coast is likely to warm by around 1.8ºC during the summer and about 1.5ºC during winter. By 2100, under the same scenario, the warming is likely to be around 3ºC at Duynefontein, 3.3ºC at Bantamsklip and 3.5ºC at Thyspunt.

Historical precipitation change over South Africa includes both drying and wetting trends depending on the region, and with significant spatial and sub-annual complexity to the signal which does not make a generalized statement possible. For the SRES A2 scenario, summer rainfall appears to remain very similar at all three sites by mid-century, whereas a decrease of about 20 mm is expected by 2100. Winter rainfall is projected to decrease by about 40 mm at Duynefontein, 45 mm at Bantamsklip and about 30 mm at Thyspunt by 2050. By 2100 the winter rainfall is projected to reduce by about 60 mm at Duynefontein, 80 mm at Bantamsklip and about 40 mm at Thyspunt. However, the complex topographical nature of these coastal sites makes it difficult to have accurate predictions. In general there are indications for slightly drier conditions at all three sites. Beyond this the messages are more complex, and hinge on the interaction of the increased atmospheric moisture content with topography and changing vertical temperature lapse rates and convection. Although there are indications that rainfall intensity is likely to increase, actual values are not currently available.

Evaporation over South Africa is likely to increase due to higher temperatures. This is likely to increase the incidence of drought potential (as defined by the response of available soil moisture and available free water), possibly even if the total rainfall of a region increases,

The winds during summer period are projected to intensify on average. By mid-century, the median wind speed would increase by about 0.4 m/s at Duynefontein and Bantamsklip and 0.2 m/s at Thyspunt. By 2100, the median wind speed would increase by about 0.7 m/s at Duynefontein, 0.8 m/s at Bantamsklip and 1.0 m/s at Thyspunt.

The current rise in ocean levels is in the order of 3 mm per year, and it is projected that ocean levels might rise further in future. The IPCC projects a 60 cm rise by 2100. However, in a recent study by Pfeffer *et al* (2008) this IPCC projection has been regarded as conservatively low. The study found that a total sea-level rise of about 2 m by 2100 could occur under physically possible glaciological conditions but only if all variables are quickly accelerated to extremely high limits. More plausible but still accelerated conditions lead to total sea-level rise by 2100 of about 0.8 m. Therefore assuming the worse-case proposal by Pfeffer *et al* (2008), it is recommended that a 2 m rise by 2100 be regarded as a maximum and that the nuclear power station need to be constructed behind the 2 m line to make sure that the risk of flooding is avoided.
.

Table 2-34: Estimated median changes in metrological parameters for the next 50 and 100 years.

Projected Change per Meteorological Parameter	Season	50 Year			100 Year		
		Duynefontein	Bantamsklip	Thyspunt	Duynefontein	Bantamsklip	Thyspunt
Temperature (degree Celsius)	Summer	1.8	1.8	1.8	3	3.3	3.5
	Winter	1.5	1.5	1.5	3	3	3
Rain (mm)	Summer	~0.0	~0.0	~0.0	-20	-20	-20
	Winter	-40	-45	-30	-60	-80	-40
Pressure (hPa)	Summer	-0.25	-0.25	-0.25	-0.5	-0.5	-0.5
	Winter	~0.0	~0.0	~0.0	~0.0	~0.0	~0.0
Mean Wind Speed (m/s)	Summer	0.4	0.4	0.2	0.7	0.8	1.0
	Winter	-0.4	-0.4	-0.3	-0.6	-0.8	-0.8
Wind Direction of predominant Wind Speed Difference	Summer	ESE	ESE	E	SE	SE	ESE
	Winter	SSE	SSE	SE	SE	SE	ESE

Notes: Projected change in average meteorological parameter derived from 15 General Circulation Models (GCMs) of the CMIP-3 archive (*see Section 2.3.5*). The 50-Year columns are for 2046-2065 based on the SRES A2 scenario (*see Section 2.3.5*) for the summer and winter seasons (average for each 6 month period). The 100-Year columns are the same, but for 2080-2099. Theses values represent the median of the 15 models.

2.4 Air Quality

Air pollution is the presence of contaminant or pollutant substances in the air that do not disperse properly and that may interfere with human health or welfare, or produce other harmful environmental effects. In the context of this study, air pollutants include non-radionuclides (i.e. conventional) and radionuclide air contaminants.

The identification of existing sources of emissions in the vicinity of the proposed sites and the characterisation of existing ambient pollutant concentrations is fundamental to the assessment of the potential for cumulative impacts and synergistic effects. This section includes current air quality levels of both non-radionuclide and radionuclide air concentrations.

Air quality limits and thresholds are fundamental to effective air quality management, providing the link between the potential source of atmospheric emissions and the user of that air at the downwind receptor site. Air quality standards are enforceable by law whilst guidelines, as used in the current context, are used primarily as an indication of the level of impact. Ambient air quality guideline values (and standards) generally indicate safe daily exposure levels for the majority of the population, including the very young and the elderly, throughout an individual's lifetime. However, setting standards may also include other factors such as economic implications.

The following section includes references to common air quality guidelines that are given in more detail in Appendix A. Air quality limits are typically set for common air pollutants which cause widespread exposures. It is normal practice to focus on the *criteria* pollutants for non-radionuclide contaminants as these represent the bulk of common emissions from industry and other manmade air pollution. Following the trend in the United States, the US EPA specified National Ambient Air Quality Standards (NAAQS) for the six most common air pollutants found all over the United States. They are airborne particulate matter, ground-level ozone, carbon monoxide, sulfur oxides, nitrogen oxides, and lead. The US EPA termed these pollutants "criteria" air pollutants because it regulates them by developing human health-based and/or environmentally-based criteria (science-based guidelines) for setting permissible levels. The set of limits based on human health is called primary standards. Another set of limits intended to prevent environmental and property damage is called secondary standards.

South Africa followed a similar trend, but extended the criteria pollutants to also include benzene (as a surrogate of volatile organic compounds) as part of the SANS 1929 Ambient Air Quality: Limits for common pollutants, discussed in Section 1.1.2. Detail of the applicable guidelines, limits and standards are summarised in Appendix A. The pollutants included in the appendix are sulfur dioxide, oxides of nitrogen (specifically nitrogen dioxide), carbon monoxide and particulate matter.

A more holistic approach is required to establish the impact of radionuclide emissions, which include all exposure pathways i.e. inhalation, cloud immersion, soil radiation and ingestion. This assessment focuses on the radionuclide impact due to air releases and deposition on soil. Therefore only preliminary results can be provided in the assessment. The comprehensive health risk assessment consolidates the radionuclide impacts from all exposure pathways. As a guideline, the public exposure dose constraint value, as discussed in Appendix A will be used as a measure of significance.

The applicable air quality criteria used in this assessment will again be discussed in Section 3.1.

2.4.1 Duynefontein

Koeberg has two uranium fuelled PWRs supplied by Framatome of France (under license from Westinghouse USA). Koeberg has two large turbine generators of over 920 MW with a total capacity to supply 1840 MW to the national grid (after internal consumption).

(a) Current Non-Radionuclide Air Quality Levels

The Duynefontein site experiences urban air pollution, including dioxide (potential sources include Chevron refinery, boilers and motor vehicle exhaust pipes), oxides of nitrogen (all combustion sources with a significant contribution from motor vehicle exhaust pipes), particulate matter (due to emissions from the petroleum refinery, boilers, other combustion sources, diesel vehicles, bush and open fires, paved and unpaved haul roads, areas exposed to wind erosion and domestic fires), and volatile organic compounds (such as benzene, toluene, xylene).

A relatively short air quality monitoring campaign at the site over three months (March 2009 to May 2009) provided background air concentrations for sulfur dioxide and nitrogen dioxide. The monthly average sulfur dioxide and nitrogen dioxide concentrations were 1.35±0.4 µg/m³ and 8.78±2.6 µg/m³, respectively.

A number of air quality monitoring stations exist in the City of Cape Town. The monitoring site in Table View is considered to be the most appropriate station for comparative purposes to the background concentration levels at the proposed nuclear power station site. Figure 2-33, Figure 2-34 and Figure 2-35 are extracted from the monthly reports produced by the City of Cape Town, Air Quality Monitoring Section, Scientific Services. These figures summarise monthly average concentrations from January 2000 to January 2007.

The long-term sulfur dioxide levels are generally low when compared to the annual average World Health Organisations (WHO) guideline of 50 µg/m³ (see Appendix A for summary of air quality guidelines). However, the monitoring results (not shown here) report regular transgressions of the WHO short-term, 10 minute guideline of 500 µg/m³. These exceedances are normally associated with southerly wind directions, i.e. blowing over Chevron refinery and other industrial areas of Cape Town. There appears to be a neutral long-term trend in sulfur dioxide concentration over this period (Figure 2-33). The onsite sulfur dioxide measurements (0.92 to 1.78 µg/m³) are considerably lower than the observations at Table View.

In contrast to sulfur dioxide, there is a clear upwards trend in ambient PM10 particulate air concentrations (Figure 2-34). An extrapolation of this trend indicates the potential to significantly exceed the annual average South African National Ambient Air Quality Standard of 40 µg/m³ (Table 3-1). Although the proposed nuclear power station site is further to the north (approximately 14 km) of the monitoring location, it is expected that the current levels of ambient particulate air concentrations would be fairly similar.

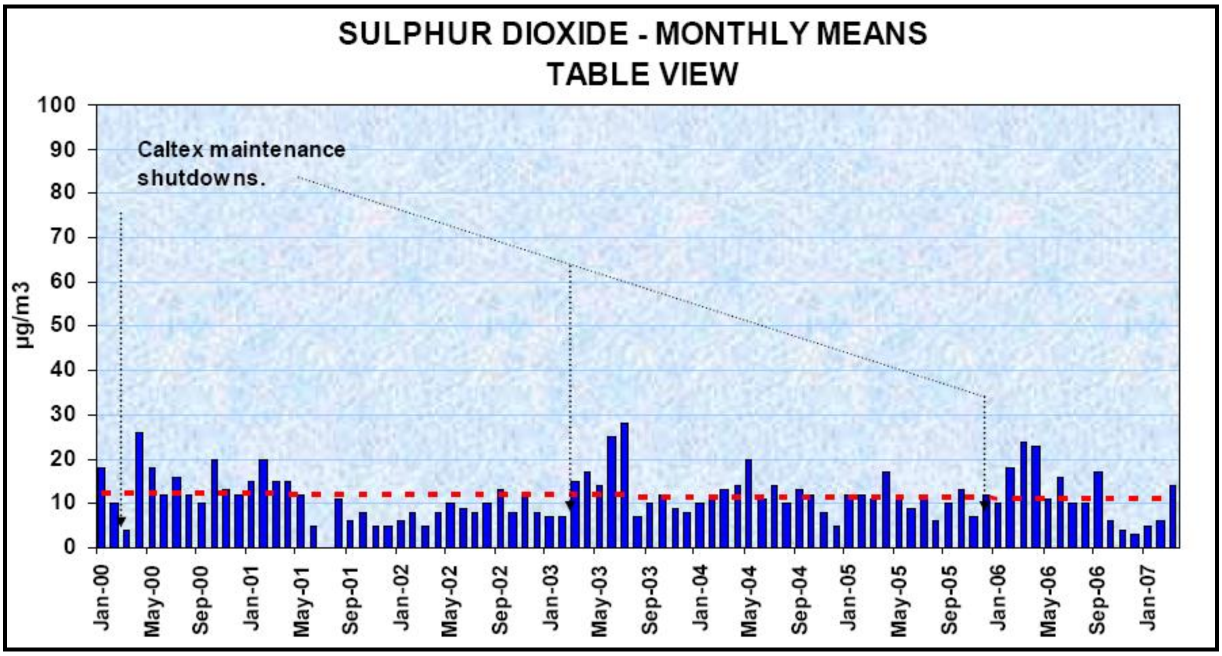


Figure 2-33: Recorded monthly mean sulfur dioxide levels in Table View. The red line indicates the linear trend

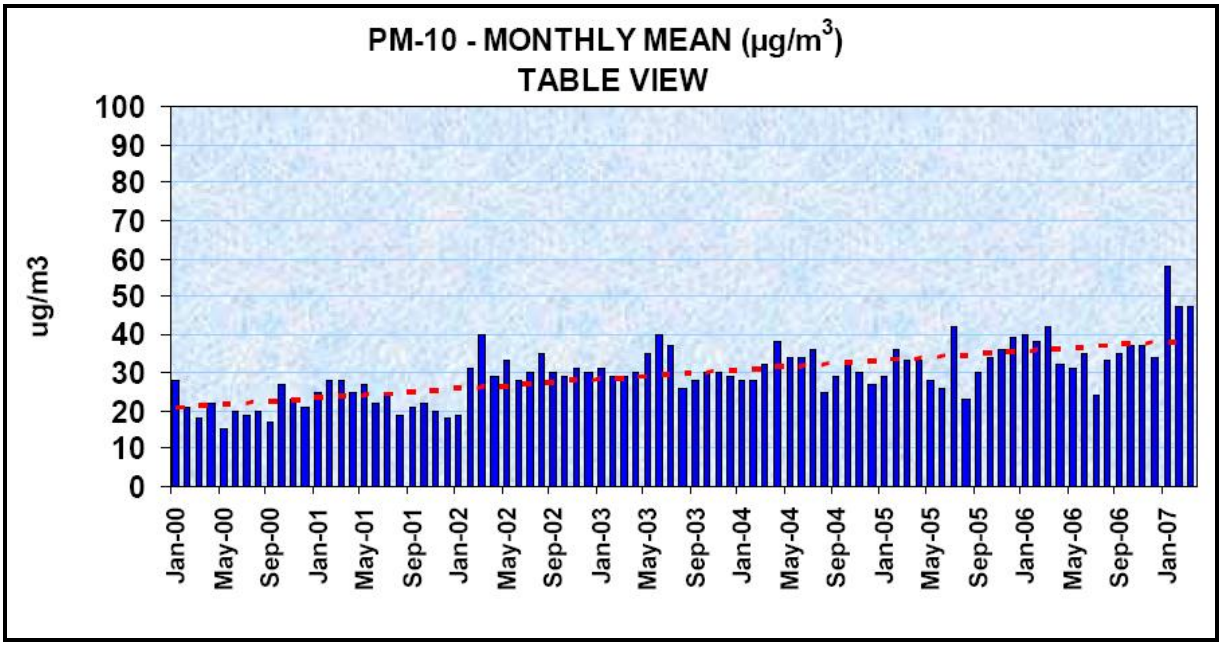


Figure 2-34: Recorded monthly mean PM10 particulate matter levels in Table View. The red line indicates the linear trend

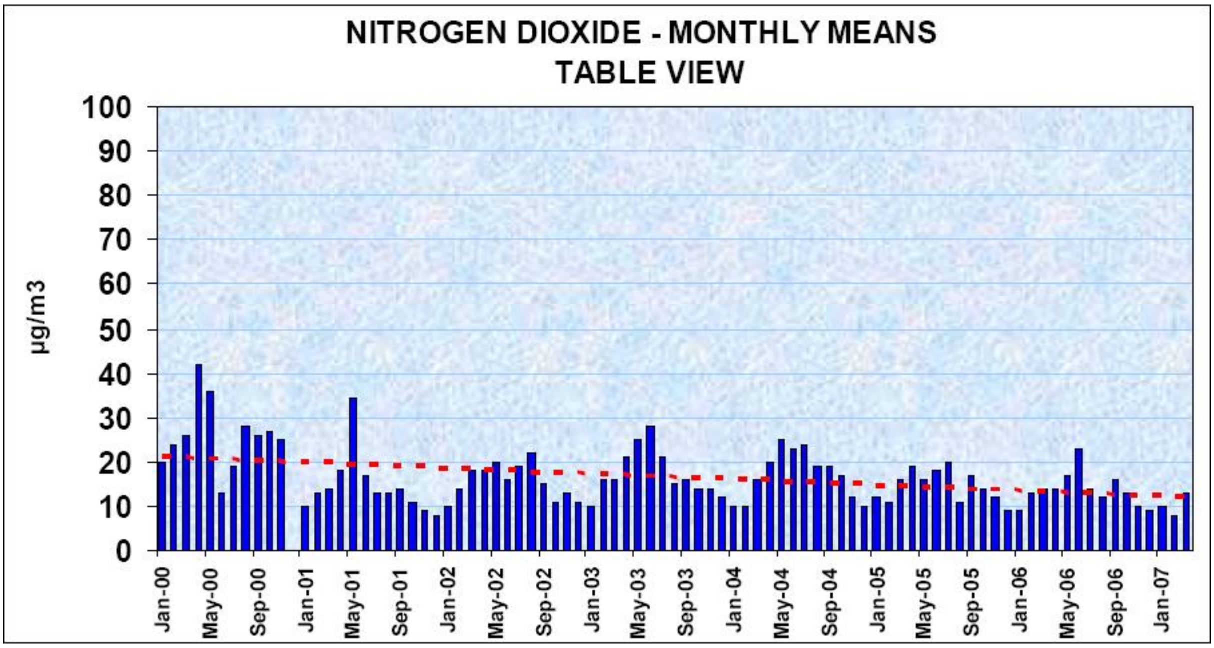


Figure 2-35: Recorded monthly nitrogen dioxide levels in Table View. The red line indicates the linear trend

An interesting downwards trend is observed in the nitrogen dioxide concentrations from 2000 to 2007, as shown in Figure 2-35. This is especially interesting since motor vehicle exhausts contribute a significant portion of this pollutant. The annual average guideline is provided by the World Health Organisation (and SANS 1929:2004) is 40 µg/m³ (Appendix A). The measurements have been below this limit. The onsite nitrogen dioxide measurements, ranging between 6.2 and 11.4 µg/m³ are relatively similar to the latest observations at Table View.

(b) Observed On-Site Radiation Dose

Based on measured gaseous emissions of nuclides, the dose at source for the period 1984 – 2008 is provided in Table 2-37.

According to the latest NNR Annual Report 2008/2009, the radioactivity in liquid and gaseous discharges from Koeberg during 2007 and 2008 contributed a projected total individual dose of 4.3 µSv to the hypothetically most exposed public group. The projected doses, as a result of gaseous and liquid discharges, were 0.47 µSv and 3.8 µSv respectively for 2008, and 0.94 µSv and 0.3 µSv respectively for 2007, which are well within the NNR limit of 250 µSv per annum, and meets the dose target of 10 µSv, which is applicable to an annual period in which there is one refuelling outage.

(c) Environmental Surveillance Programme

Eskom currently runs an environmental surveillance programme at the Koeberg Environmental Survey Laboratory (ESL). The results of the environmental surveillance programme are contained in annually produced Environmental Survey Laboratory (ESL) reports

The pre-operational phase of the environmental survey programme was conducted from 1979 to June 1981. The operational environmental survey programme immediately followed the pre-operational phase, taking cognisance that Koeberg's unit 1 and unit 2 only achieved operation in 1984 and 1985 respectively.

Air particulate samples have been collected from indicator sites, as well as from control sites further afield. The indicator sites include Horticulture, the ESL, the Disaster Management Offices (DMO) at Duynefontein, the Edusec complex, the Med Centre (NNR), SA Cable Company and Watertank.

Malmesbury is a control site. Control sites are locations considered to be far enough from Koeberg to not be affected by its operations. Activity found at such locations is considered to be representative of general activity levels in the environment.

No radionuclides attributable to Koeberg's power operation have been detected in the air particulate samples. Pre-operationally ^{110m}Ag, ^{60}Co, ^{134}Cs, ^{137}Cs, and ^{54}Mn were detected at both indicator and control sites (Table 2-35), while operationally, radioactivity other than naturally occurring radioactivity was detected in 1987, 2008 and 2009 (Table 2-36).

Table 2-35: Observed air particulate activity prior to the operation of Koeberg Nuclear Power Station (Bq/m³)

Date	Location	^{110m}Ag	^{60}Co	^{134}Cs	^{137}Cs	^{131}I	^{54}Mn
Aug 1981	ESL	-	-	1.00E-5	-	-	-
Feb 1982	Med Centre (NNR)	-	-	-	-	-	4.00E-5
Jun 1982	SA Cable Company	3.00E-4	-	-	-	-	-
Jun 1982	ESL	-	6.00E-5	-	-	-	-
Aug 1982	ESL	-	-	-	-	-	5.00E-5
Oct 1982	Med Centre (NNR)	-	4.00E-5	-	-	-	-
Dec 1982	Watertank	-	4.00E-5	-	-	-	-
Mar 1983	SA Cable Company	-	-	7.00E-5	-	-	-
Dec 1983	Watertank	-	-	-	9.00E-5	-	-
Dec 1983	Malmesbury	-	-	-	1.20E-4	-	-

"-" denotes Not Detected

It is stipulated (GGS-1309, "Radiation Protection – Environmental Surveillance") that a ^{137}Cs activity detected at a level of 0.0374 Bq/m³ requires an in-depth investigation of its presence. Although the levels detected during 2008 and 2009 were below this threshold, an investigation was nonetheless initiated to determine whether Koeberg Power Station was responsible for these traces. The conclusions made in the ESL 2008 and ESL 2009 reports were that it is unlikely that Koeberg was the source of the ^{137}Cs activity detected in the iodine cartridge. This conclusion is supported by both (a) the analyses of prevailing weather conditions and (b) the detection of ^{137}Cs activity in unused cartridges, showing that the charcoal used in the cartridges could well have been contaminated.

Table 2-36: Observed air particulate activity during the operation of Koeberg Power Station (Bq/m³)

Date	Location	^{110m}Ag	^{60}Co	^{134}Cs	^{137}Cs	^{131}I	^{54}Mn
Jan 1987	Med Center (NNR)	-	-	-	-	1.00E-3	-
Jan 1987	Watertank	-	-	-	2.81E-1	-	-
Feb 1987	Watertank	-	-	-	-	8.00E-4	-
Apr 1987	ESL	-	-	-	-	-	7.50E-2
Aug 1987	SA Cable Company	-	-	-	-	1.10E-3	-
Sep 1987	SA Cable Company	-	-	-	-	1.10E-3	-
Aug 2008	Edusec	-	-	-	3.13E-4	-	-
Sep 2008	Horticulture	-	-	-	1.90E-4	-	-
Sep 2008	DMO	-	-	-	1.88E-4	-	-
Sep 2008	Malmesbury	-	-	-	2.81E-4	-	-
Sep 2008	Malmesbury	-	-	-	3.71E-4	-	-
March 2009	Edusec	-	-	-	3.35E-4	-	-
March 2009	Edusec	-	-	-	3.38E-4	-	-

"-" denotes Not Detected

In addition, direct radiation monitoring is done by employing two sets of thermoluminescent dosimeters (TLDs) (Radiological Environmental Survey, 2008 and 2009):

- Twenty nine (29) TLDs are located in roughly 3 concentric rings (the majority of these TLDs are located so that there is at least one in each geographical sector) and are replaced on a monthly basis:
  - the inner perimeter fence (IPF): 0.6 km to 1 km;
  - the public exclusion boundary (PEB):1.5 km to 2.9 km;
  - rural areas: 3.3 km to 10.5 km from Koeberg.
- Nineteen (19) TLDs are located further afield and are replaced every three months and are located as follows:
  - urban areas such as Mamre, Atlantis, Table View, Milnerton, Durbanville, Epping, Pinelands, Woodstock, Sea Point, and Robben Island; and
  - the rest of the TLDs are located on farms.

Monitored data for the period 1992 to 2008 was obtained for assessment. The TLD data are presented in units of µSv/month to facilitate comparisons in all locations.

Table 2-37: Radiation dose for the period 1984 – 2008 (Eskom and NNR Annual Reports 2007/2008 and 2008/2009).

Year of Observation	Dose (µSv)
1984	0.006
1985	0.083
1986	0.532
1987	0.164
1988	0.353
1989	0.285
1990	0.221
1991	0.393
1992	0.231
1993	0.200
1994	0.186
1995	0.160
1996	0.388
1997	0.309
1998	0.101
1999	0.170
2000	0.143
2001	0.289
2002	0.191
2003	0.339
2004	1.062
2005	0.484
2006	0.413
2007	0.940
2008	0.470

The TLD readings at the IPF (0.6 km to 1 km) for 1992 to 2008 are given in Figure 2-36. The readings reflect the monthly average in each of nine wind directions over land. These ambient doses via TLDs are not due to the operation of the Koeberg plant but are due to the gamma radiation emitted from naturally occurring radioactive material (NORM) in road-construction materials. All the TLD's are positioned in the vicinity of dirt or tarred roads containing high levels of natural radioactivity.

A reduction in the reported dose was observed from 2000 due to a change in the TLD dose assessment process as approved by the NNR. The maximum reading (recorded during 2008) for the past five years was 40 µSv/month.

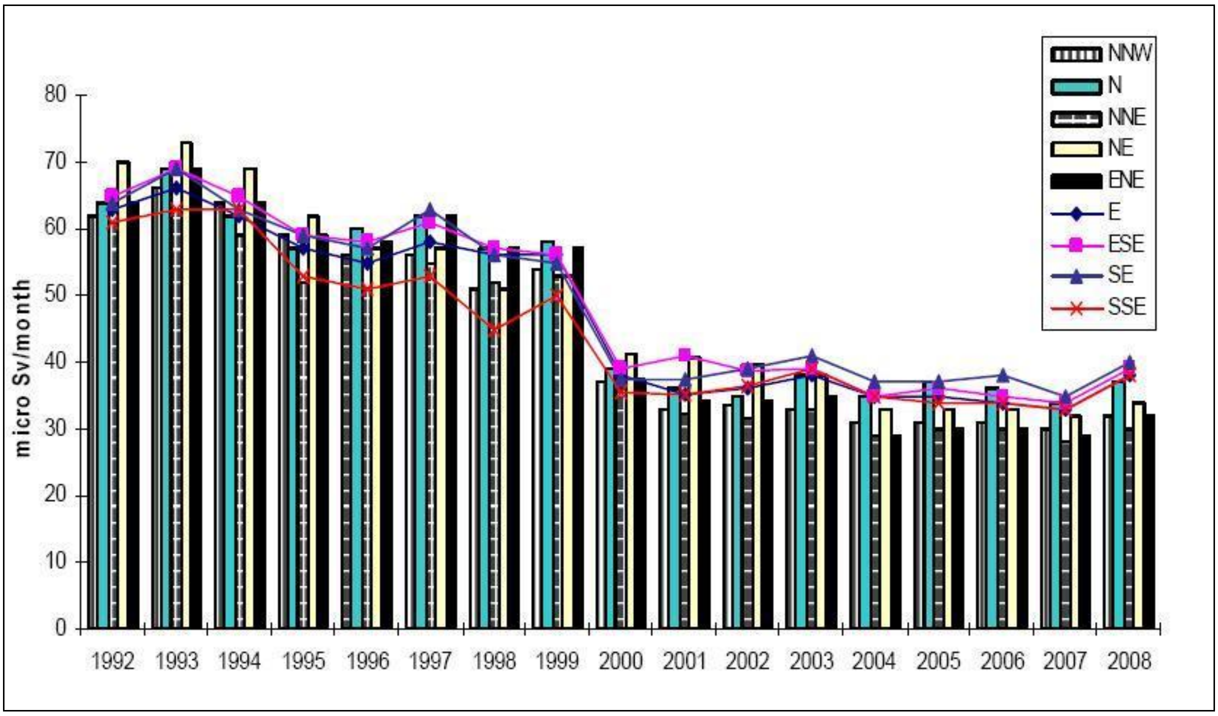


Figure 2-36: Inner perimeter fence TLD annual average readings 1992 to 2008

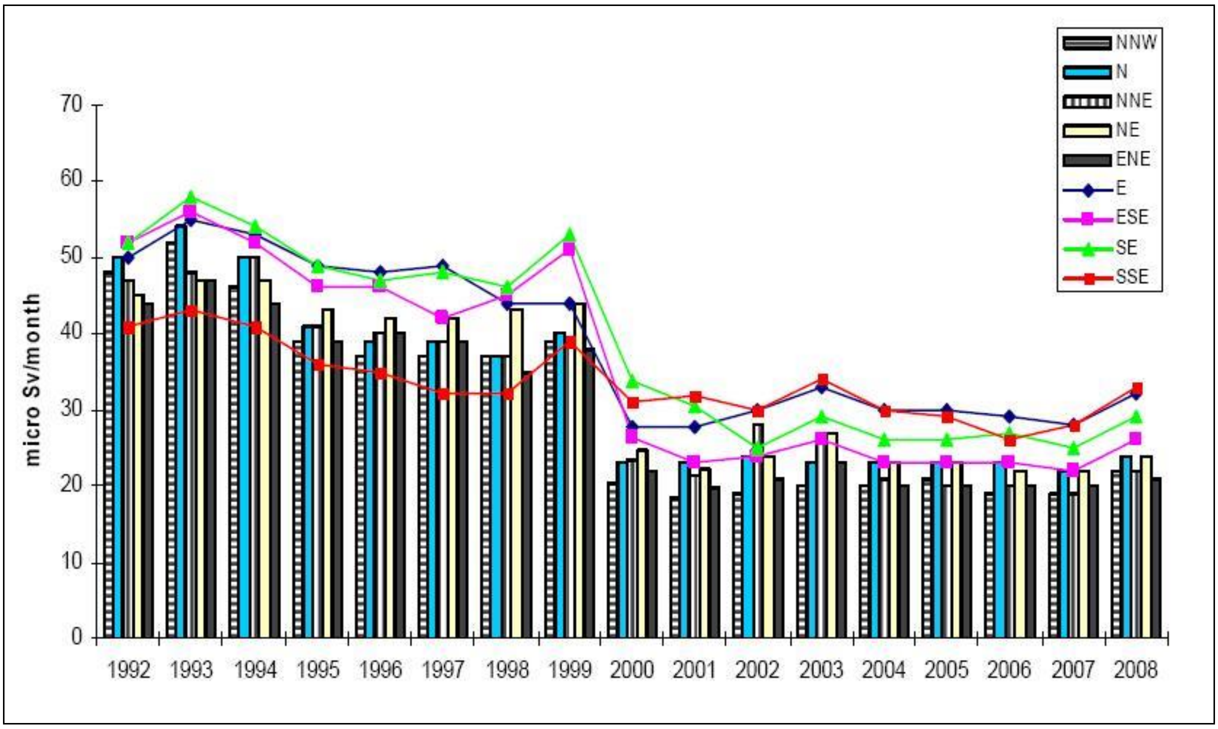


Figure 2-37: Public exclusion boundary annual average TLD readings 1992 to 2008

Further away, at the PEB (1.5 km to 2.9 km), the TLD readings were lower, with the maximum reading (recorded during 2008) for the past five years being 33 µSv/month. This is shown in Figure 2-37.

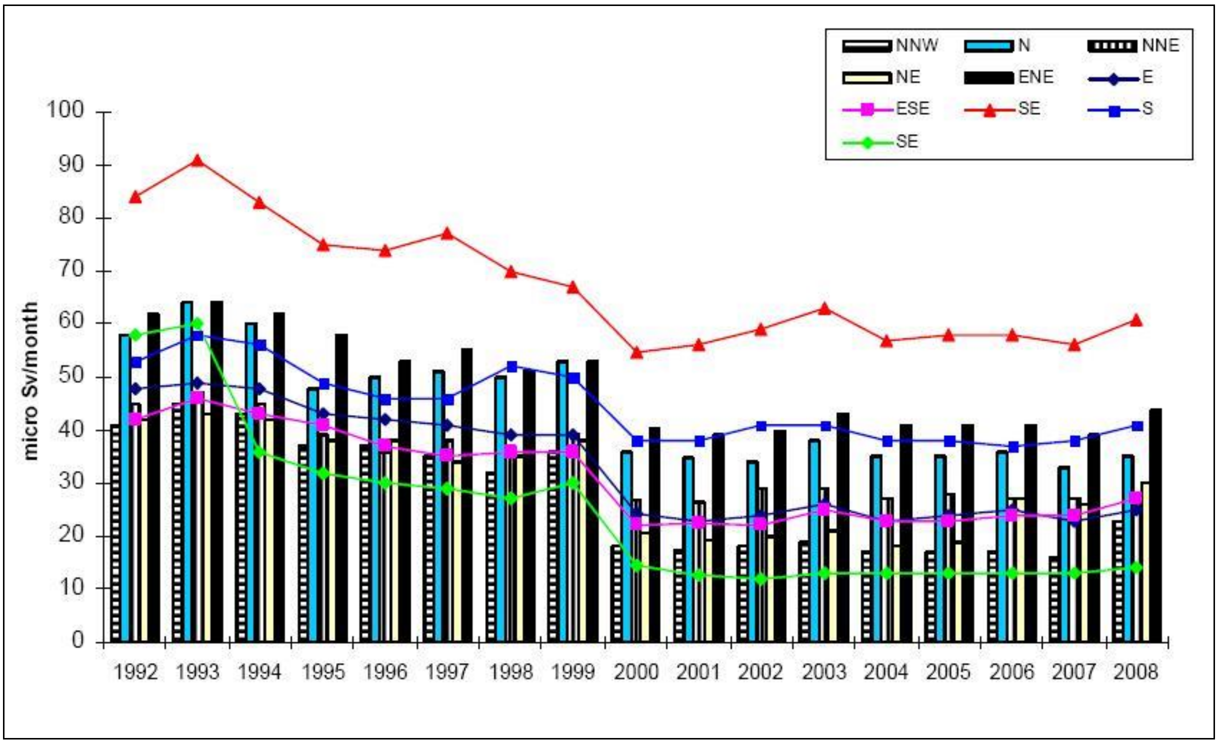


Figure 2-38: Rural annual average TLD readings 1992 to 2008

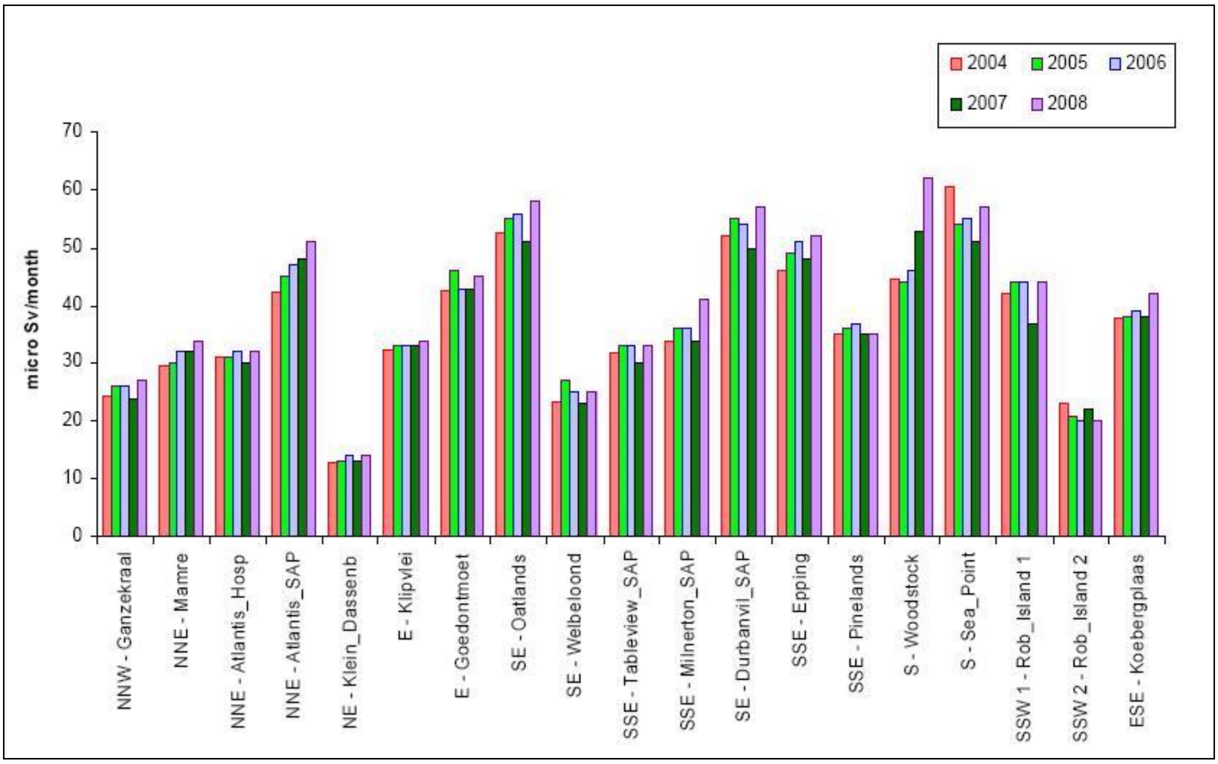


Figure 2-39: TLD readings for 2004 to 2008 at distant locations

Figure 2-38 is a summary of the TLD readings for 1992 to 2008 in the rural areas, 3.3 km to 10.5 km from Koeberg. The highest reading during the past five years was 61 µSv/month.

The annual average, quarterly TLD readings at distant locations is summarised in Figure 2-39. The highest reading during the past five years was 62 µSv/month, recorded in Woodstock.

(d) Radionuclide Dispersion Model Results

Based on the measured nuclide emission releases for Koeberg for the period 1984 – 2003 (Appendix B), the spatial radiation dose per annum was predicted. Figure 2-40 illustrates the highest dose distribution. The year's emission that resulted in the highest effective dose due to inhalation was used for the compliance of impact.

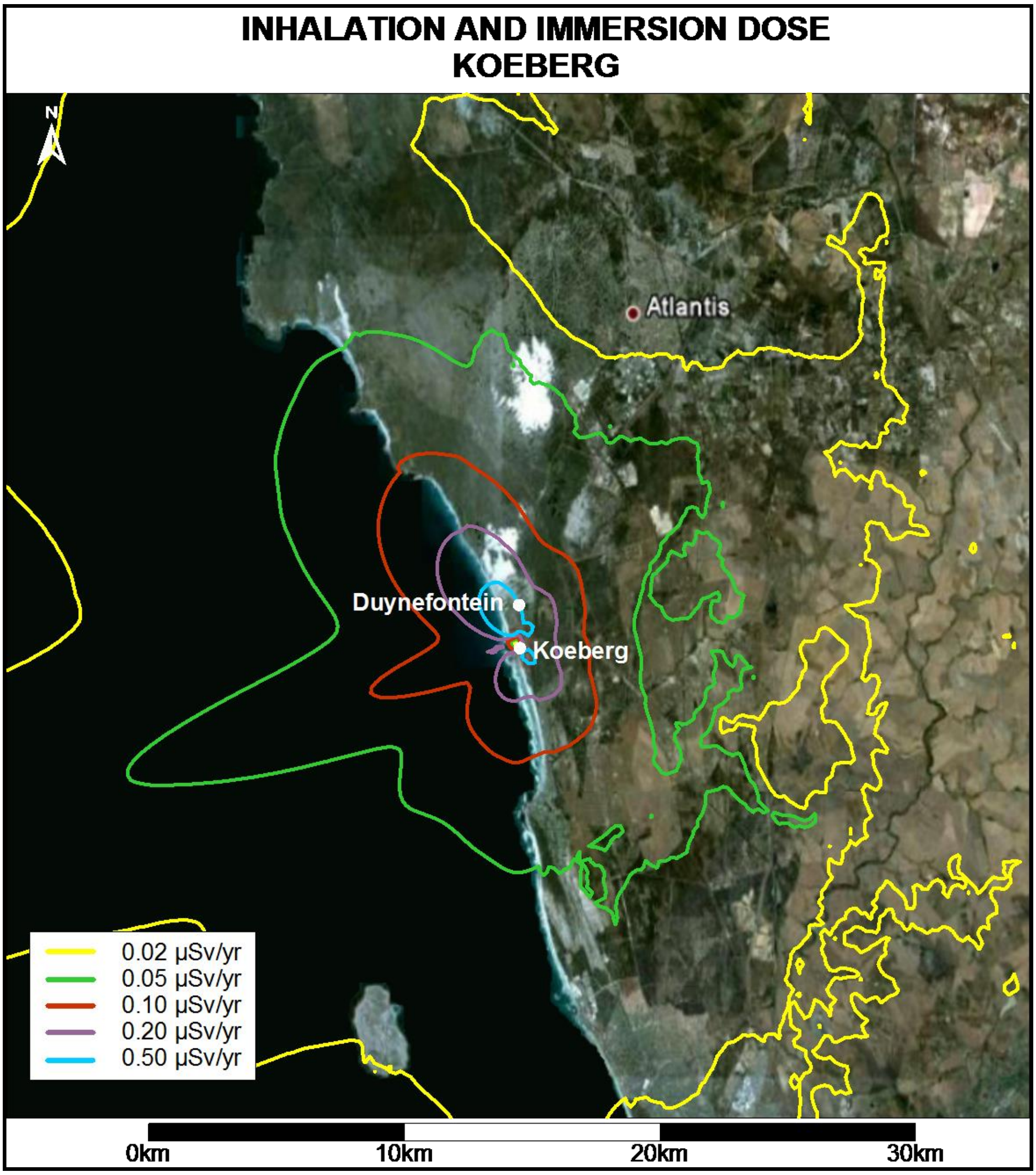


Figure 2-40: Predicted maximum annual inhalation and immersion radiation dose (µSv) for Koeberg

The emissions included 27 radionuclides and are given in Becquerels per annum (Bq/a). These nuclides may not necessarily all occur in all these years. For example, Strontium-90 has been noted to occur only once (2003) during this period (i.e. $2x10^5$

Bq/a). Ceasium-137 occurred eight times with the maximum during 1994 of $2x10^7$ Bq/a. Argon-41, Iodine-131 to 135, and the noble gases Krypton and Xenon are the most common radionuclide releases.

The highest on-site inhalation and immersion radiation dose for Koeberg was predicted to be 1.8 µSv, approximately 875 m north-northwest of the power station. The highest inhalation and immersion radiation dose predicted in a radius of 2 km from the power station is 0.7 µSv, also north-northwest of the power station. Based on the NNR regulations (Appendix A), the highest predicted dose is less than 0.2 % of the annual effective dose limit of 1000 µSv for members of the public and about 0.7 % of the dose constraint of 250 µSv[15]. Similarly, the maximum predicted dose at a distance of 2 km Koeberg is less than 0.1 % of the annual effective dose limit and less than 0.3 % of the dose constraint.

2.4.2 Bantamsklip

Unfortunately, no ambient air quality monitoring network exists at the Bantamsklp site and therefore no historical data are available. A relatively short air sampling campaign was, however, completed for a three-month period from March to May 2009. The observed monthly average sulfur dioxide and nitrogen dioxide concentrations were 0.63 µg/m³ and 1.76 µg/m³, respectively.

These concentrations reflect the conditions in the absence of any industrial activities in the vicinity. The closest source of potential industrial air pollution would be from Hermanus, approximately 44 km northwest of the site. Local sources of air pollution include vehicle emissions from the nearby Pearly Beach and along the R43, fires (both domestic and runaway) and any activities that can generate fugitive dust emissions (e.g. farming activities).

2.4.3 Thyspunt

Similar to Bantamsklip, no ambient air sampling data are available to provide historical air pollution concentration quantities at Thyspunt. A three-month sampling exercise was completed during March to May 2009. The observed monthly average sulfur dioxide and nitrogen dioxide concentrations were 0.40 µg/m³ and 1.51 µg/m³, respectively. These concentrations are considered to be low and typical of conditions away from air pollution generating activities.

The closest source of potential air pollution is Oyster Bay, approximately 3 km from the proposed nuclear power station site. The air emissions typically include fugitive

[15] Government Notice No. R 388 of 2009 specifies that the annual *effective dose limit* for members of the public from all authorised actions is 1 000 µSv (Appendix A) with an additional provision of an *annual dose constraint* of 250 µSv.

- The effective dose limit is defined in terms of incremental dose, which is the dose resulting from the nuclear power station only. The natural background radiation, including radon, is excluded from the dose limitations. Radiation dose arising from the application of medical procedures is also excluded from the dose limitations.
- A dose constraint is an upper value on the annual dose that members of the public or incidentally exposed workers should receive from a planned operation or single source. To ensure that the public and incidentally exposed workers do not exceed the annual dose limit of 1 mSv, the NNR suggest the use of a dose constraint of 250 µSv. The dose constraint would allow for exposures from other sources without the annual limit being exceeded. The retrospective finding that a dose constraint, as opposed to a dose limit, has been exceeded does not imply a failure to comply with the Regulations. Rather it should call for a reassessment of the effectiveness of the program.

dust from building activities and unpaved road surfaces, and combustion products from domestic fires and vehicle emissions. Due to the sparse population, these emissions are not considered significant.

The increased human activities at Cape St. Francis would result in increased levels of air pollution. However, it is located 13 km east of the site and would therefore have minimal impact at the site. The relatively more industrialised Humansdorp is located approximately 18 km north of the site, but with the easterly and westerly prevailing winds, offer little opportunity to carry air pollution to the proposed nuclear power station site.

3 IMPACT IDENTIFICATION AND ASSESSMENT

The air quality impacts of the proposed nuclear power station are expected to occur with construction, operation, and decommissioning phases. Only non-radioactive emissions would occur during the construction period, whereas radionuclide emissions may additionally also be associated with the operational phase. The applicable air quality criteria for determining the significance of impacts from the proposed nuclear power station are summarised in Section 3.1. A more general account is provided in Appendix A.

3.1 Air Pollution Impact Criteria

3.1.1 Non-Radionuclide Criteria

(a) Criteria Pollutants

Table 3-1 summarises the National Ambient Air Quality Standards used by the DEA.

Table 3-1: National Ambient Air Quality Standards

Pollutant	Averaging Period	Limit Value ($\mu g/m^3$)	Limit Value (ppb)	Frequency of Exceedance	Compliance Date
Carbon Monoxide (CO)	1 hour	30000	26000	88	Immediate
	8 hour[(a)]	10000	8700	11	Immediate
Nitrogen Dioxide (NO_2)	1 hour	200	106	88	Immediate
	1 year	40	21	0	Immediate
PM10	24 hour	120	-	4	Immediate – 31 Dec 2014
	24 hour	75	-	4	1 Jan 2015
	1 year	50	-	0	Immediate – 31 Dec 2014
	1 year	40	-	0	1 Jan 2015
Sulphur Dioxide (SO_2)	10 minutes	500	191	526	Immediate
	1 hour	350	134	88	Immediate
	24 hour	125	48	4	Immediate
	1 year	50	19	0	Immediate

As a comparison, the World Health Organisation (WHO) health risk guidelines have been provided in Table 3-2. These include guidelines for sulfur dioxide, nitrogen dioxide and carbon monoxide.

Table 3-2: Applicable World Health Organisation air quality guidelines.

Pollutant		Maximum 10-minute Average ($\mu g/m^3$)	Maximum 1-hourly Average ($\mu g/m^3$)	Maximum 24-hour Average ($\mu g/m^3$)	Annual Average Concentration ($\mu g/m^3$)
Sulfur Dioxide (a)	WHO	500	-	20	-
	DEA		350	125	50
Nitrogen Dioxide	WHO	-	200(b)		-
	DEA		200		40
Carbon Monoxide (c)	WHO	-	30 000	10 000 [8-hourly]	-
	DEA	-	30 000	10 000	-
Inhalable Particulate Matter (PM10)	WHO	-	-	(d)	(d)
	DEA	-	-	75	40

NOTES:
(a) WHO Air Quality Guidelines, Global Update, 2005 – Report on a Working Group Meeting, Bonn, Germany, 18-20 October 2005. Documents new WHO guidelines primarily for the protection of human health. The 10-minute guideline of 500 $\mu g/m^3$ published in 2000 remains unchanged but the daily guideline is significantly reduced from 125 $\mu g/m^3$ to 20 $\mu g/m^3$ (in line with the precautionary principle). An annual guideline is given at not being needed, since "compliance with the 24-hour level will assure lower levels for the annual average".
(b) WHO Guidelines for the protection of human health (WHO, 2000). AQGs remain unchanged according to WHO (2005).
(c) WHO Guidelines for the protection of human health (WHO, 2000).
(d) WHO (2000) issues linear dose-response relationships for PM10 concentrations and various health endpoints. No specific guideline given.

No specific limits or health endpoints for PM10 are provided. During the 1990s the WHO stated that no safe thresholds could be determined for particulate exposures and responded by publishing linear dose-response relationships for PM10 and PM2.5 concentrations (WHO, 2005).

This approach was not well accepted by air quality managers and policy makers. As a result the WHO Working Group on Air Quality Guidelines recommended that the updated WHO air quality guideline document contain guidelines that define concentrations which, if achieved, would be expected to result in significantly reduced rates of adverse health effects.

These guidelines would provide air quality managers and policy makers with an explicit objective when they were tasked with setting national air quality standards. Given that air pollution levels in developing countries frequently far exceed the recommended WHO air quality guidelines (AQGs), the Working Group also proposed interim target (IT) levels, in excess of the WHO AQGs themselves, to promote steady progress towards meeting the WHO AQGs (WHO, 2005).

The air quality guidelines and interim targets issued by the WHO in 2005 for particulate matter are given in Table 3-3 and Table 3-4

Table 3-3: WHO air quality guideline and interim targets for particulate matter (annual mean) (WHO, 2005).

Annual Mean Level	PM10 (µg/m³)	PM2.5 (µg/m³)	Basis for the selected level
WHO interim target-1 (IT-1)	70	35	These levels were estimated to be associated with about 15% higher long-term mortality than at AQG
WHO interim target-2 (IT-2)	50	25	In addition to other health benefits, these levels lower risk of premature mortality by approximately 6% (2-11%) compared to WHO-IT1
WHO interim target-3 (IT-3)	30	15	In addition to other health benefits, these levels reduce mortality risks by another approximately 6% (2-11%) compared to WHO-IT2 levels.
WHO Air Quality Guideline (AQG)	20	10	These are the lowest levels at which total, cardiopulmonary and lung cancer mortality have been shown to increase with more than 95% confidence in response to PM2.5 in the American Cancer Society (ACS) study (Pope et al., 2002 as cited in WHO 2005). The use of the PM2.5 guideline is preferred.

Table 3-4: WHO air quality guideline and interim targets for particulate matter (daily mean) (WHO, 2005)

Annual Mean Level	PM10 (µg/m³)	PM2.5 (µg/m³)	Basis for the selected level
WHO interim target-1 (IT-1)	150	75	Based on published risk coefficients from multi-centre studies and meta-analyses (about 5% increase of short-term mortality over AQG)
WHO interim target-2 (IT-2) (a)	100	50	Based on published risk coefficients from multi-centre studies and meta-analyses (about 2.5% increase of short-term mortality over AQG)
WHO interim target-3 (IT-3) (b)	75	37.5	Based on published risk coefficients from multi-centre studies and meta-analyses (about 1.2% increase of short-term mortality over AQG)
WHO Air Quality Guideline (AQG)	50	25	Based on relation between 24-hour and annual levels

NOTES:
(a) 99th percentile (3 days/year)
(b) for management purposes, based on annual average guideline values; precise number to be determined on basis of local frequency distribution of daily means

(b) Dust Deposition

Dust deposition is evaluated according to the criteria published by DEA. In terms of these criteria dust deposition is classified as follows:

SLIGHT - less than 250 mg/m²/day

MODERATE	-	250 to 500 mg/m²/day
HEAVY	-	500 to 1200 mg/m²/day
VERY HEAVY	-	more than 1200 mg/m²/day

The Department of Minerals and Energy (DME) uses the 1 200 mg/m²/day threshold level as an action level. In the event that on-site dustfall exceeds this threshold, the specific causes of high dustfall should be investigated and remedial steps taken.

The SANS 1929:2004 proposed that dustfall rates be evaluated against a four-band scale, as presented in Table 3-5 with the target, action and alert thresholds for ambient dust deposition are given in Table 3-6.

Table 3-5: Bands of dustfall rates proposed for adoption

BAND No.	BAND DESCRIPTION LABEL	DUST-FALL RATE (D) (mg m^{-2} day^{-1}, 30-day average)	COMMENT
1	RESIDENTIAL	D < 600	Permissible for residential and light commercial
2	INDUSTRIAL	600 < D < 1 200	Permissible for heavy commercial and industrial
3	ACTION	1 200 < D < 2 400	Requires investigation and remediation if two sequential months lie in this band, or more than three occur in a year.
4	ALERT	2 400 < D	Immediate action and remediation required following the first exceedance. Incident report to be submitted to relevant authority.

Table 3-6: Target, action and alert thresholds for ambient dustfall

LEVEL	DUST-FALL RATE (D) (mg m^{-2} day^{-1}, 30-day average)	AVERAGING PERIOD	PERMITTED FREQUENCY OF EXCEEDANCES
TARGET	300	Annual	
ACTION RESIDENTIAL	600	30 days	Three within any year, no two sequential months.
ACTION INDUSTRIAL	1 200	30 days	Three within any year, not sequential months.
ALERT THRESHOLD	2 400	30 days	None. First exceedance requires remediation and compulsory report to authorities.

According to the proposed dustfall limits, an enterprise may submit a request to the authorities to operate within the Band 3 ACTION band for a limited period, providing that this is essential in terms of the practical operation of the enterprise (for example the final removal of a tailings deposit) and provided that the best available control technology is applied for the duration. No margin of tolerance will be granted for operations that result in dustfall rates in the Band 4 ALERT.

(c) Formaldehyde and Ammonia

The California Office of Environmental Health Hazard Assessment (OEHHA, 1999) derived an acute toxicity guideline for formaldehyde based on eye irritation, which would be protective against mild adverse effects.

The recommended exposure limit was estimated by a benchmark concentration approach, using log-probit analysis. The 95 per cent lower confidence limit of the concentration expected to produce a response rate of five per cent for exposure of one hour duration to formaldehyde was 0.94 mg/m³. An uncertainty factor of 10 was applied to account for the observed wide variability in human response to formaldehyde exposure. The acute 1-hour exposure guideline of 0.094 mg/m³ (94 µg/m³) is judged to be protective for assessment of acute exposure of members of the public to formaldehyde.

Most of the U.S. states have adopted the inhalation Reference Concentration (RfC) of 100 µg/m³ for ammonia, which has been derived by the US Environmental Protection Agency for their long-term guidelines. This value has also been adopted in this investigation.

(d) Odorous Compounds

Both formaldehyde and ammonia are also associated with potential odours. Odours are primarily a nuisance, but suggestions exist that it is possible for certain odorous emissions to have an impact on physical health. The most frequently reported symptoms attributed to odours include headache, nausea, hoarseness, cough, nasal congestion, palpitations, shortness of breath, stress, drowsiness, alterations in mood, and eye, nose, and throat irritation. Odours are a complex mixture of gases, vapours, and even airborne particulates. The potential health impact of any odour depends upon the concentration of odorous emissions as well as the frequency and duration of exposure. Since these emissions are not expected to occur frequently, it may not be a cause for concern.

Olfactory acuity (the ability to smell a certain odour) in the population follows a lognormal distribution. Two percent are predictably hypersensitive and two percent are insensitive. The insensitive range includes those who are unable to smell at all (anosmic) and those who are partially unable to smell (hyposmic). A person may be relatively insensitive to one smell and abnormally sensitive to another. Since the significance of an odour could vary between individuals, a number of definitions have been proposed. In Verscheuren's (1996) Handbook of Environmental Data on Organic Chemicals, three different odour thresholds have been defined: the absolute perception threshold, the recognition threshold, and the objectionability threshold. At the perception threshold concentration, one is barely certain that an odour is detected. The recognition thresholds normally used are the 50% and the 100% thresholds. These percentages refer to the statistical averages of the odour panel results: the 50% Recognition Threshold refers to the concentration at which 50% of the odour panel defined the odour as being representative of the odorant being studied. Similarly, the 100% Recognition Threshold refers to the concentration at which 100% of the odour panel defined the odour as being representative of the odorant being studied.

Odour recognition concentrations can vary significantly and may cover several orders of magnitude. For example, hydrogen sulphide (characteristic smell of rotten egg), has a perception threshold of less than 1 µg/m³, a 50% Recognition Threshold of about 10 µg/m³ and a 100% Recognition Threshold of about 1 000 µg/m³. Similarly, ammonia, which has an extremely pungent smell at relatively high concentrations, has a 10% recognition threshold of about 200 µg/m³, a 50 % Recognition Threshold of about 3 000 µg/m³ and a 100% Recognition Threshold of about 60 000 µg/m³. The human odour perception level for formaldehyde is 70 µg/m³ and the 50 % odour recognition concentration is about 100 µg/m³.

3.1.2 Radionuclide Impact Criteria

Appendix A includes a summary of the NNR dose limits and constraints (Government Notice No. R.388 of 2006 (DME 2006) (also see footnote 15). The maximum annual average effective dose limit for visitors to the sites and those not deemed to be occupationally exposed is 1 mSv (1000 µSv). The annual dose equivalent limit for individual organs and tissues of such persons is 10 mSv.

The annual effective dose limit for members of the public from all authorised actions is 1 mSv. No action may be authorised which would give rise to any member of the public receiving a radiation dose from all authorised actions exceeding 1 mSv in a year.

The NNR Regulation R388 of 2006 additionally provides a dose constraint, which is applicable to an average member of the critical group within the exposed population. This effective dose should not exceed 0.25 mSv (or 250 µSv) in a year from potential exposure from the site.

A dose limit for events such as design basis accidents is not specified in Government Notice No. R. 388 of 2006. In a separate document the NNR specifies an accumulated total individual design dose limit of 50 mSv per event (NNR, 2007).

3.2 Predicted Impact during Construction Phase

3.2.1 Emission Inventory

Air emissions during construction include airborne particulates and gaseous emissions. However, airborne particulates are considered to potentially result in significantly higher impact than the gaseous pollutants. This could be both as inhalable air concentrations and dust fallout levels.

The size of the construction footprint for the nuclear power station could vary between the technologies, with an estimated footprint of approximately 60 ha to 280 ha. For the purposes of this investigation, the larger footprint was used in the calculations and therefore a more conservative estimate. This size was assumed for all three sites. The sites are on undeveloped ground, so there would be no demolition operations. The existing vegetation density on the Thyspunt site is significantly higher than at the Duynefontein and Bantamsklip sites. Land clearing is therefore expected to be more significant at Thyspunt. The natural ground to topsoil at all sites is approximately 0.3 m deep. The amount of topsoil to be removed and stored at the three sites has been estimated as follows:

Thyspunt : 229 456 m³
Bantamsklip : 197 850 m³
Duynefontein : 183 920 m³

The excavation of the sands at all three sites will proceed to bedrock, while the excavation in bedrock will proceed to a sufficient depth to accept the plant foundations. The soil amounts for removal have been estimated as follows:

Thyspunt : 5 753 741 m³
Bantamsklip : 8 202 746 m³
Duynefontein : 4 468 248 m³

Further excavation for the plant foundations down to bedrock at -3 mamsl at Thyspunt and Bantamsklip, and -4 mamsl at Duynefontein result in the following soil and rock amounts:

Thyspunt : 2 136 561 m³ (sand) and 289 276 m³ (rock)
Bantamsklip : 3 762 828 m³ (sand)
Duynefontein : 4 344 860 m³ (sand)

Backfilling from bedrock to +10 mamsl requires the following amounts:

Thyspunt : 1 360 759 m³
Bantamsklip : 1 696 708 m³
Duynefontein : 2 180 059 m³

The rock to be excavated from the average bedrock at -3 mamsl (Thyspunt and Bantamsklip) and -4 mamsl (Duynefontein) to the Intake Basin at -16 mamsl have been estimated to be as follows:

Thyspunt : 381 795 m³
Bantamsklip : 1 161 306 m³
Duynefontein : 1 245 065 m³

Further excavation is also required for the Intake Tunnel System, which is assumed to be approximately 1 000 m long at a level of about -35 masml. The rock to be excavated for this is as follows:

Thyspunt : 37 285 m³
Bantamsklip : 37 285 m³
Duynefontein : 37 285 m³

The preparation of the High Voltage Yard requires the following soil amounts:

Thyspunt : 157 616 m³ (at +111 mamsl)
Bantamsklip : 195 593 m³ (at +38 mamsl)
Duynefontein : 153 285 m³ (at +38 mamsl)

An accurate calculation of emissions during the construction period is generally not possible due to the requirement of detailed information, which only becomes available at the final stages of the project. However, typical construction activities, such as scraping, excavation, loading, offloading and haulage were all included in the calculation of the emissions inventory. Wind erosion of exposed surfaces such as topsoil storage piles and open construction areas were also accounted for in the calculations. These emission rates were calculated using emission factors developed by the US EPA and the Australian National Pollution Inventory.

Table 3-7: Calculated airborne particulate emission rates for construction, assuming no unpaved access roads to site and no mitigation at construction site

Activity	Source	Duynefontein				Bantamsklip				Thyspunt			
		Emissions (tpa)		% Contribution		Emissions (tpa)		% Contribution		Emissions (tpa)		% Contribution	
		TSP	PM10	TSP	PM10	TSP	PM10	TSP	PM10	TSP	PM10	TSP	PM10
Topsoil Removal	Scraping	3.55	1.85	0.098%	0.172%	3.67	1.91	0.044%	0.072%	8.04	4.18	0.081%	0.137%
	Materials Handling	1.56	0.55	0.043%	0.051%	1.88	0.66	0.023%	0.025%	4.55	1.59	0.046%	0.052%
	Wind Erosion	0.03	0.01	0.001%	0.001%	0.02	0.01	0.000%	0.000%	2.75	0.89	0.028%	0.029%
	Vehicle Entrainment	1.67	0.38	0.046%	0.035%	2.40	0.74	0.029%	0.028%	7.63	2.48	0.077%	0.081%
	TOTAL	*6.81*	*2.78*	*0.187%*	*0.258%*	*7.96*	*3.31*	*0.096%*	*0.124%*	*22.97*	*9.14*	*0.231%*	*0.300%*
Excavation to Bedrock	Excavation	455.79	237.01	12.53%	22.035%	596.55	310.20	7.196%	11.647%	737.01	383.25	7.398%	12.582%
	Materials Handling	146.93	51.43	4.04%	4.781%	223.22	78.13	2.693%	2.933%	305.26	106.84	3.064%	3.507%
	Wind Erosion	0.73	0.40	0.02%	0.037%	0.07	0.02	0.001%	0.001%	5.25	1.80	0.053%	0.059%
	Vehicle Entrainment	3017.49	780.55	82.95%	72.566%	7453.94	2268.97	89.921%	85.193%	8880.76	2540.94	89.138%	83.417%
	TOTAL	*3620.95*	*1069.39*	*99.54%*	*99.419%*	*8273.77*	*2657.32*	*99.811%*	*99.774%*	*9928.28*	*3032.82*	*99.652%*	*99.565%*
Backfilling	Materials Handling	9.92	3.47	0.27%	0.323%	7.73	2.71	0.093%	0.102%	11.72	4.10	0.118%	0.135%
	TOTAL	*9.92*	*3.47*	*0.27%*	*0.323%*	*7.73*	*2.71*	*0.093%*	*0.102%*	*11.72*	*4.10*	*0.118%*	*0.135%*
TOTAL		3637.67	1075.64	100%	100%	8289.46	2663.34	100%	100%	9962.97	3046.06	100%	100%

The following additional assumptions were made:

- A period of 18 months was assumed for the land preparation, i.e. excavation work only;
- Construction activities were assumed to take place for 10 hours per day;
- The exact location of the plant layout as well as the spoil and topsoil stockpiles were unknown for the current assessment. For the purposes of the assessment, the nuclear power station was placed on the extreme west and east boundaries of the corridor to assess the maximum impacts off-site. Similarly the stockpiles were placed in close location to the plant with shortest routes assumed for the roads from the plant to the stockpiles.
- The particle size distributions assumed in the calculations were based on a number of representative samples on each of the three sites. These locations were based on the proposed location of the corridor, as well as the different dune field varieties, i.e. Pleistocene and Holocene;
- The average weight of the haul trucks on site was assumed to be 17.5 tonnes (taking into consideration the truck being empty and full); and
- From the vehicles entering the site, 2% are assumed to be trucks with 98% assumed to be vehicles transporting workers and consumables.

The airborne particulate emission rates for the various activities were calculated using the emission factors discussed in Appendix B. Table 3-7 is a summary of the unmitigated emission rates.

The US EPA (US EPA 1995) developed an emission factor based on field measurements of total suspended particulate concentrations surrounding apartment and shopping centre construction projects. The average emission factor for construction is:

E = 2.69 tonnes per hectare per month of activity

This value is of interest for comparison to the above calculated emissions. Using the calculated emission rates for the construction site only and the area of construction, the factors for the three sites are:

Thyspunt : *2.13 tonnes per hectare per month of activity*
Bantamsklip : *1.63 tonnes per hectare per month of activity*
Duynefontein : *1.22 tonnes per hectare per month of activity*

Although the US EPA factor overestimates the emissions at the three sites, it is fairly similar.

Clearly, wheel entrainment is responsible for the majority of total particulate emissions, and contributes about 83% at Duynefontein, 90% at Bantamsklip and 89% at Thuyspunt. Excavation is the next largest source, contributing about 13% at Duynefontein and 7% each at Bantamsklip and Thuyspunt.

3.2.2 Predicted Air Quality Impact

As discussed in Section 1.2.3, it was decided to employ the US EPA's AERMOD dispersion model for the purposes of predicting all atmospheric emissions during the construction phase.

AERMOD requires two specific input files generated by the AERMET pre-processor. AERMET is designed to be run as a three-stage processor and operates on three types of data (upper air data, on-site measurements, and the national meteorological database).

On-site surface meteorological data were obtained from the closest meteorological station to the three sites. In order to account for annual differences, the closest weather station with the longest hourly average meteorological dataset have been utilised in the simulations. Therefore, due to the extended monitoring period, the South African Weather Service (SAWS) Station of Cape St. Francis for the period 2004 – 2007 was selected for Thyspunt; and the SAWS station of Hermanus for the period 2000-2007 was selected for Bantamsklip. The on-site Koeberg meteorological data for the period 2002 – 2006 were selected for Duynefontein. Upper air data were obtained from the calculated ETA modelled data from the South African Weather Services for the periods

The dispersion of particulate matter during the construction period was modelled for an area covering ~10km (north-south) by ~7km (east-west) for Duynefontein; ~10km (north-south) by ~7km (east-west) for Bantamsklip; and ~5.5km (north-south) by ~8km (east-west) for Thyspunt. This area was divided into a grid with a resolution of 150 m. AERMOD simulates ground-level concentrations for each of the receptor grid points.

Topography was included for dispersion modelling purposes. Use was made of the Shuttle Radar Topography Mission (SRTM) 90m Digital Elevation Model (DEM) Data. The SRTM 90 m DEM is available as 3 arc second (approx. 90 m resolution).

(a) Duynefontein

Figure 3-1 and Figure 3-2 summarise the maximum predicted inhalable particulate air concentration and deposition rate for the construction phase at Duynefontein. These predictions exclude any mitigation measures. The most significant impact is predicted to occur along the unpaved access road. The distance at which it is predicted that the 120 $\mu g/m^3$ limit value (for compliance until end of 2014) will be exceeded is about 900 m. The 75 $\mu g/m^3$ limit (for compliance from 2015) is predicted to be exceeded up to 1.4 km from the road.

Fallout of larger particles normally occurs near the generating source, as shown in Figure 3-2. The fallout rate permissible for residential and light commercial land use is 600 mg/m^2 per day. The distance to this value is about 126 m. The distance to the SLIGHT fallout rate of 250 mg/m^2 per day is about 223 m.

(b) Bantamsklip

The predicted particulate unmitigated impact during the construction phase at Bantamsklip is given in Figure 3-3 and Figure 3-4 for the maximum air concentration and deposition rate, respectively. The distance at which it is predicted that the 120 $\mu g/m^3$ limit will be exceeded is about 2.5 km (north of the site). Similarly, the 75 $\mu g/m^3$ limit is predicted to be exceeded up to 3.0 km from the site.

As shown in Figure 3-4, the fallout is quite significant; with the rate permissible for residential and light commercial (600 mg/m^2 per day) predicted to be exceeded up to a distance of about 0.7 km. The distance to the SLIGHT fallout rate of 250 mg/m^2 per day is about 1.4 km.

Figure 3-1: Predicted maximum daily average inhalable particle (PM10) concentration levels (µg/m³) during construction at Duynefontein (Unmitigated)

Figure 3-2: Predicted maximum daily average particle fallout rates (mg/m²/day) during construction at Duynefontein (Unmitigated)

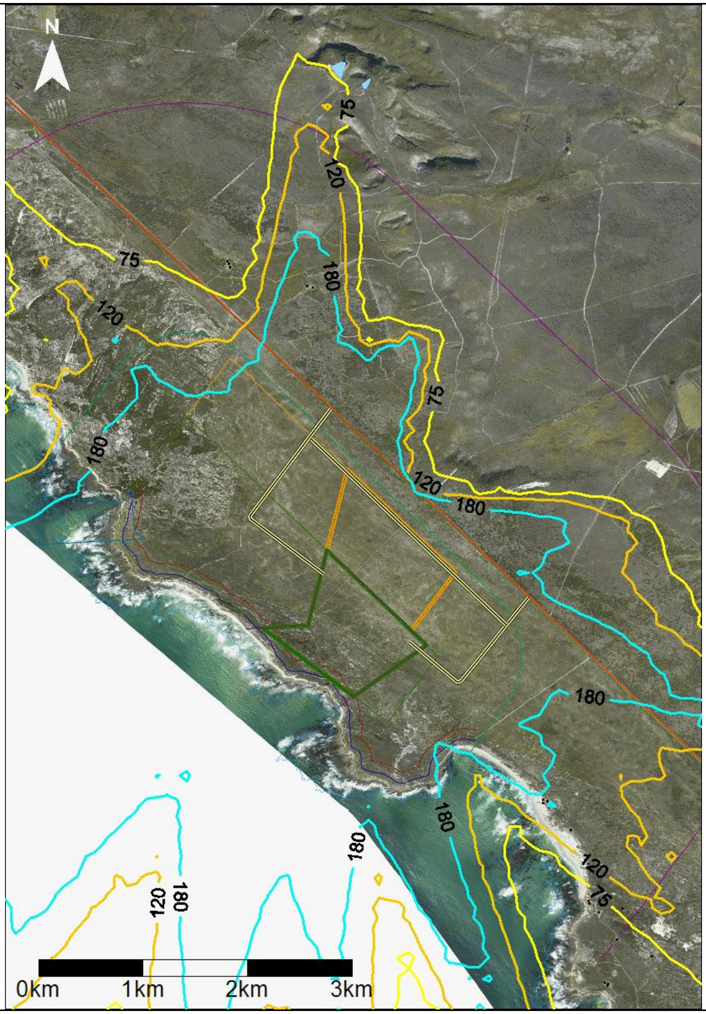


Figure 3-3: Predicted maximum daily PM10 concentration levels (µg/m³) during construction at Bantamsklip (Unmitigated)	**Figure 3-4: Predicted maximum daily average particle fallout rates (mg/m²/day) during construction at Bantamsklip (Unmitigated)**

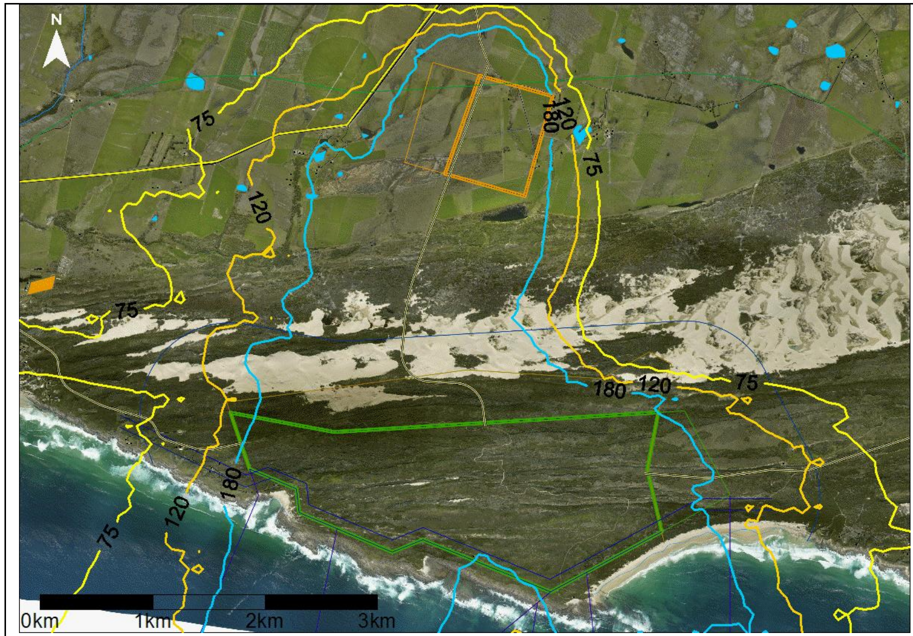


Figure 3-5: Predicted maximum daily average PM10 concentration levels (µg/m³) during construction at Thyspunt with Road Option A and the envelope of the nuclear power station on the east or west of the corridor (Unmitigated)

Figure 3-6: Predicted maximum daily average particle fallout rates (mg/m²/day) during construction at Thyspunt with Road Option A and the envelope of the nuclear power station on the east or west of the corridor (Unmitigated)

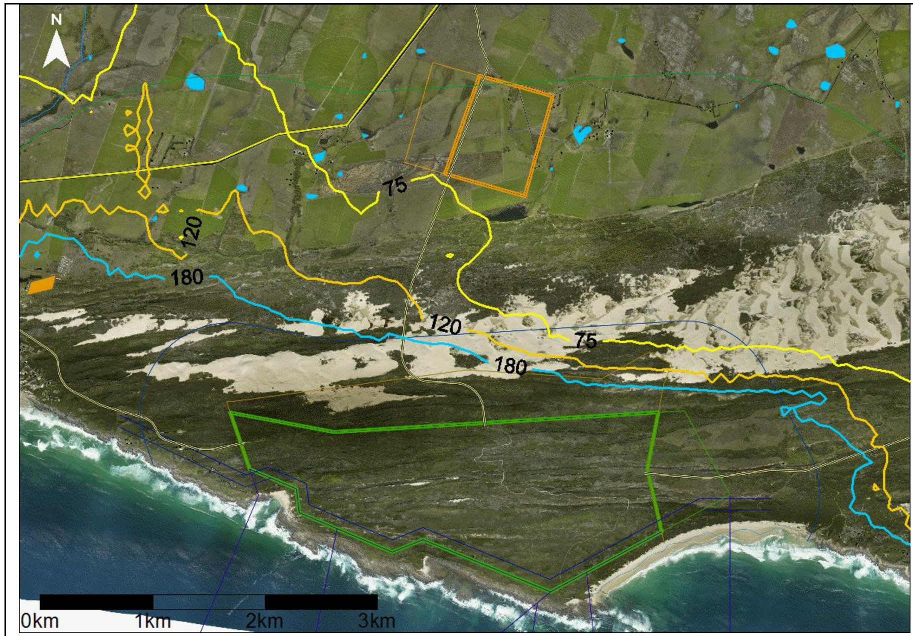


Figure 3-7: Predicted maximum daily average PM10 concentration levels (µg/m³) during construction at Thyspunt with Road Option B and the envelope of the nuclear power station on the east or west of the corridor (Unmitigated)	**Figure 3-8: Predicted maximum daily average PM10 concentration levels during construction at Thyspunt with Road Option C and the envelope of the nuclear power station on the east or west of the corridor (Unmitigated)**

(c) Thyspunt

Three different access road options were considered in the Thyspunt simulations. With Option A the road enters the site from the north. The road passes through Oyster Bay in Option B. Option C is for the access to be from the eastern side of the site.

The predicted unmitigated PM10 concentrations for these three road options are given in Figure 3-5 (Option A), Figure 3-7 (Option B) and Figure 3-8 (Option C). Figure 3-6 summarises the fallout rate for Option A. These figures include the envelope of the two possible construction locations, located on the eastern and western parts of the corridor. The simulations for the individual sites did not show any preference.

As with Duynefontein, the most significant impact is predicted to occur along the unpaved access road. The distance at which it is predicted that the 120 µg/m³ limit will be exceeded is about 1.4 km. The 75 µg/m³ limit is predicted to be exceeded up to 2.1 km from the road.

As shown in Figure 3-6, the fallout is quite significant; with the rate permissible for residential and light commercial (600 mg/m² per day) predicted to be exceeded up to a distance of about 0.6 km. The distance to the SLIGHT fallout rate of 250 mg/m² per day is about 1.1 km.

3.3 Predicted Impact during the Operational Phase

3.3.1 Non-radioactive emissions

(a) Emissions Inventory

Potential sources of air emissions (non-radioactive) during operation include:

- Particulates, sulfur dioxide, oxides of nitrogen and carbon monoxide in the exhaust gases from engines of the backup electricity generators;
- Formaldehyde and carbon monoxide emitted by the insulation when installations go back into operation after servicing; and
- Ammonia discharged as the temperature rises in the steam generators during start-up.

(i) Combustion Gases

It is proposed that there would be three auxiliary steam boilers, each capable of producing 32 t/h steam. These boilers would be operated using diesel as fuel. Furthermore, it is proposed to have four emergency diesel generators with a capacity of 8 MW and two station blackout generators with a capacity of 3 MW. The backup generators are tested periodically (2 hours per week) to ensure they are in good working order. In addition, it is proposed that there would be two gas turbines, each rated at 25 MWe gross output power.

These are safety equipment, providing a backup power supply if the main supply is interrupted, so that the units can be secured and the reactors cooled. During these operations, combustion gases that will be produced include mainly airborne particulates, sulfur dioxide, oxides of nitrogen, carbon monoxide and carbon dioxide.

Since these units operate intermittently, it was decided to prepare the impact assessment using the largest units, i.e. the two, 25 MW gas turbines. Furthermore, the assessment of combustion gases was based on the Siemens SGT-700 design.

The stack parameters and emission rates of the primary pollutants are summarised in Table 3-8. It was given that the fuel requirement would be 1.74kg/s. Diesel has a typical sulphur level of 0.05%.

Table 3-8: Air emissions from backup power supply generators

Parameter		Value
Stack Design		
	Release Height	30 m
	Stack Diameter	4.5 m (i.e.4 m x 4 m)
Operating Conditions		
	Exit Gas Velocity	13 to 15 m/s, used 14.7 m/s
	Exit Gas Temperature	773 to 811 K, used 773 K
	Mass Flow Rate	100 kg/s (max), used 85 kg/s
Pollutant Emission Rates per Unit		
	Sulfur Dioxide	1.74 g/s (used 0.05% S in fuel)
	Carbon Monoxide	2.5 g/s (25 ppmv or 30 mg/Nm^3)
	Oxides of Nitrogen	6.7 g/s (42 ppmv or 80 mg/Nm^3)
	Particulates	4.2 g/s (assume <50 mg/Nm^3)

(ii) Formaldehyde and carbon monoxide

The following emissions apply to a single reactor unit. However, these units would under normal circumstances not be shut for maintenance at the same time. These emissions are therefore considered to be the maximum at any one time.

When the nuclear power station restarts after maintenance, the temperature rises and the insulation in the reactor building undergoes some thermal decomposition. It produces steam containing formaldehyde within the containment in the reactor building, and this in turn may produce carbon monoxide.

In order to keep the concentrations of formaldehyde and carbon monoxide in the workplace air below the acceptable exposure limits, the discharged gases are evacuated via a chimney by operating the reactor building ventilation system, at either normal or low flow rates, depending on the condition of the unit.

The quantities of formaldehyde and carbon monoxide discharged as gases into the environment when the unit is restarted after maintenance have been calculated by considering a worst-case scenario. Restarting the installation produces approximately 700 g of formaldehyde and 660 g of carbon monoxide in the containment in the reactor building. The operating time required to evacuate these quantities to comply with the average exposure limits depends on the ventilation flow rate in the reactor building containment. It is estimated at eight hours at normal flow rates and 42 hours at low flow rates.

(iii) Ammonia

If the Reactor Unit is shut down for longer than a week, keeping the steam generators wet during this period prevents their fabric corroding and provides a biological barrier (a water shield) when carrying out work in the vicinity of the equipment. In this case, the steam generators are filled with demineralised water, conditioned with hydrazine with added morpholine, ethanolamine or ammonia in the proportions defined in the chemical specifications for the shutdown period.

Once the shutdown is over, the solution used for wet lay-up can be drained into the reservoirs or heated directly in the steam generators as the installation restarts. The gaseous effluent from this process is then evacuated using the turbine bypass to the atmosphere.

The rise in temperature generates gaseous ammonia from the wet lay-up solution and the emergency feed water system for the steam generators. It is assumed that all the hydrazine present in the water is broken down into ammonia.

The quantity of discharged ammonia is estimated to be approximately 20 kg. The assumption is that this quantity is discharged during the first few hours of operation, which is considered to be small. The chemicals discharged from the unit that may produce an odour are formaldehyde, ammonia and diesel exhaust gases.

(b) Dispersion Model

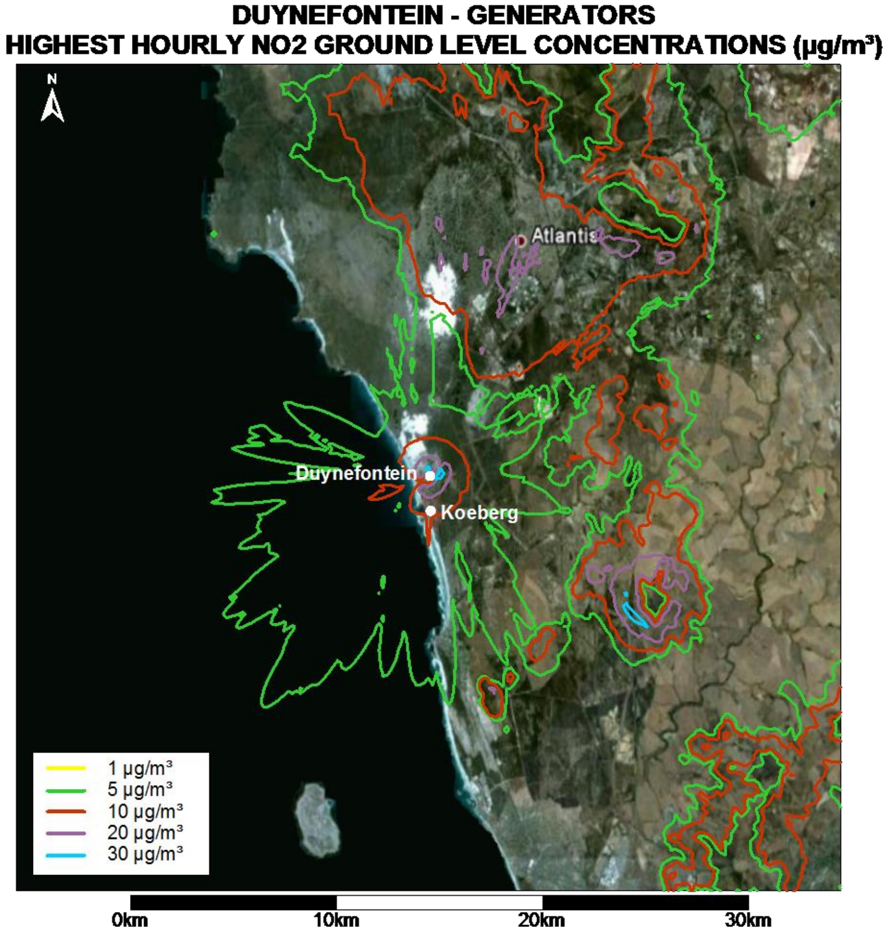
Similar to the construction phase, it was decided to employ the US EPA's AERMOD dispersion model for the purposes of predicting all atmospheric emissions during the operational phase.

The dispersion of pollutants was modelled for an area covering 40 km (north-south) by 40 km (east-west). This area was divided into a grid with a resolution of ~200 m. The proposed nuclear power station was placed in the centre of the modelling domain. Topography was included on the same grid resolution. Within the immediate vicinity of the site, the topography is relatively undulating. However, the topography further afield is mountainous.

(c) Predicted Impacts

The emissions of formaldehyde and ammonia are very infrequent and relatively low, and are not expected to exceed any guidelines. The highest hourly average formaldehyde concentrations predicted at Duynefontein, Bantamsklip and Thyspunt are 0.12 µg/m^3, 0.30 µg/m^3 and 0.19 µg/m^3, respectively. This is very low when compared to the 1-hour exposure guideline of 94 µg/m^3, which was derived by the California Office of Environmental Health Hazard Assessment (OEHHA, 1999) for assessment of acute exposure of members of the public to formaldehyde.

The highest hourly average ammonia concentrations predicted at Duynefontein, Bantamsklip and Thyspunt are 14.3 µg/m^3, 35.0 µg/m^3 and 21.8 µg/m^3, respectively. It is lower than the US EPA's inhalation Reference Concentration (RfC) of 100 µg/m^3. The predicted short-term ammonia and formaldehyde concentrations are also below the odour recognition concentrations of 200 µg/m^3 (10% odour recognition level) and 70 µg/m^3 (odour perception), respectively.



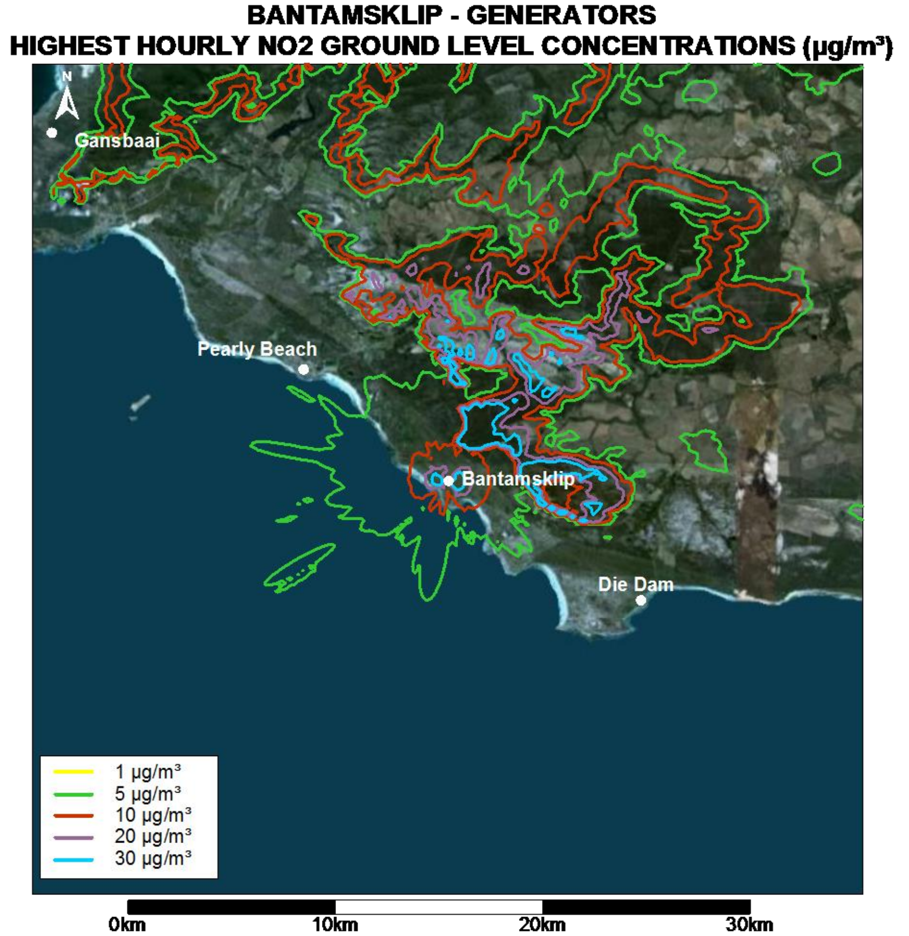


Figure 3-9: Predicted maximum hourly average nitrogen dioxide concentration from backup generators at Duynefontein

Figure 3-10: Predicted maximum hourly average nitrogen dioxide concentration from backup generators at Bantamsklip

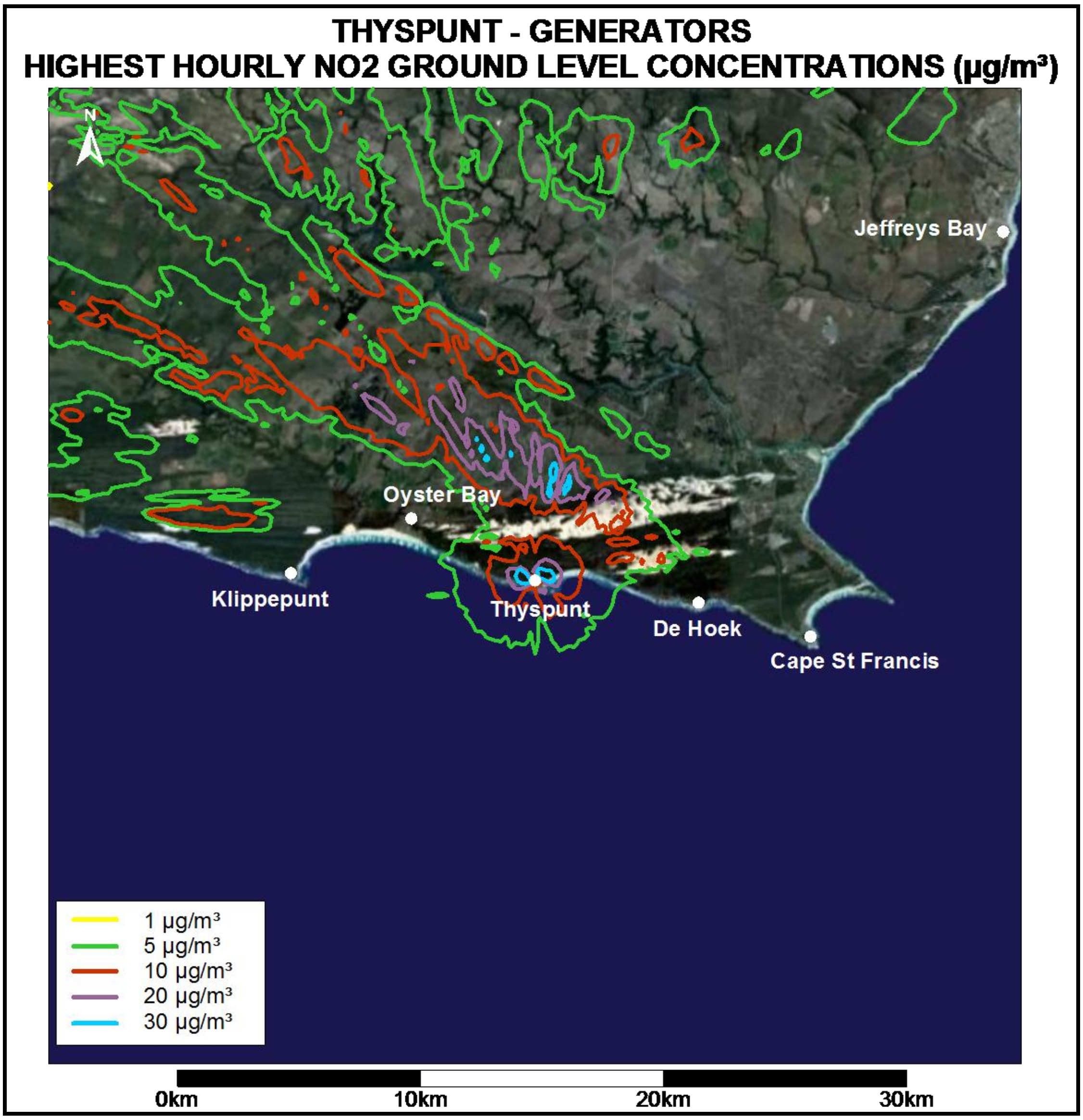


Figure 3-11: Predicted maximum hourly average nitrogen dioxide concentration from backup generators at Thyspunt

The highest hourly average predicted ground level nitrogen dioxide concentrations resulting from the operation of the two 25 MWe gas turbines are shown in Figure 3-9, Figure 3-10 and Figure 3-11, for the Duynefontein, Bantamsklip and Thyspunt sites, respectively. The spatial distributions for the other pollutants (SO_2, CO and PM10) are similar and therefore not shown here.

The predicted ground level concentrations of pollutants resulting from the operation of the two 25 MWe backup generators are low compared with the relevant air concentration guidelines. This is clearly evident from the comparison against the respective guidelines in Table 3-9 (Duynefontein), Table 3-10 (Bantamsklip) and Table 3-11 (Thyspunt).

Table 3-9: Comparison of maximum predicted air concentrations resulting from operation of Backup Electricity Generators against air quality limits (Duynefontein)

Pollutant	Averaging Period	Air Concentrations (µg/m³)		
		Predicted	Limit	Fraction of Limit
PM10	Highest daily	6.5	150 (b, h) 100 (c) 75 (d, g) 50 (e, f)	0.04 0.07 0.09 0.13
	Annual average	0.5	70 (b) 50 (c, h) 40 (g) 30 (d, f) 20 (e, f)	<0.01 0.01 0.01 0.02 0.03
SO_2	Highest hourly	9.0	350 (f)	0.03
	Highest daily	2.7	150 (h) 125 (b, f, g) 50 (c) 20 (e)	0.02 0.02 0.05 0.14
	Annual average	0.2	80 (8) 50 (g) 20 (f)	<0.01 <0.01 0.01
NO_2	Highest hourly	34.6	200 (e, f, g)	0.17
	Highest daily	10.3	150 (h)	0.07
	Annual average	0.2	100 (h) 40 (e, f, g)	<0.01 <0.01
CO	Highest hourly	12.9	30 000 (f)	<0.01

Notes:
(a) The IFC and World Bank Group state that in the absence of national legislated standards (as in the case of Namibia), the current WHO Air Quality Guidelines or other internationally recognised sources should be used.
(b)) WHO interim target-1.
(c) WHO interim target-2 (For SO_2 this interim target is stated as being a reasonable and feasible goal for developing countries).
(d) WHO interim target-3.
(e) WHO guideline value.
(f) EC directive.
(g) National Ambient Air Quality Standard.
(h) World Bank - Thermal Power: Guidelines for New Plants – Ambient Air Quality.

Table 3-10: Comparison of maximum predicted air concentrations resulting from operation of Backup Electricity Generators against air quality limits (Bantamsklip)

Pollutant	Averaging Period	Air Concentrations (µg/m³)		
		Predicted	Limit	Fraction of Limit
PM10	Highest daily	9.8	150 (b, h) 100 (c) 75 (d, g) 50 (e, f)	0.07 0.10 0.13 0.20
	Annual average	0.5	70 (b) 50 (c, h) 40 (g) 30 (d, f) 20 (e, f)	<0.01 0.01 0.01 0.02 0.03
SO_2	Highest hourly	21.9	350 (f)	0.06
	Highest daily	4.0	150 (h) 125 (b, f, g) 50 (c) 20 (e)	0.03 0.03 0.08 0.20
	Annual average	0.2	80 (8) 50 (g) 20 (f)	<0.01 <0.01 0.01
NO_2	Highest hourly	84.3	200 (e, f, g)	0.42
	Highest daily	15.6	150 (h)	0.10
	Annual average	0.7	100 (h) 40 (e, f, g)	<0.01 0.02
CO	Highest hourly	31.4	30 000 (f)	<0.01

Notes:
(a) The IFC and World Bank Group state that in the absence of national legislated standards (as in the case of Namibia), the current WHO Air Quality Guidelines or other internationally recognised sources should be used.
(b)) WHO interim target-1.
(c) WHO interim target-2 (For SO_2 this interim target is stated as being a reasonable and feasible goal for developing countries).
(d) WHO interim target-3.
(e) WHO guideline value.
(f) EC directive.
(g) National Ambient Air Quality Standard.
(h) World Bank - Thermal Power: Guidelines for New Plants – Ambient Air Quality.

Table 3-11: Comparison of maximum predicted air concentrations resulting from operation of Backup Electricity Generators against air quality limits (Thyspunt)

Pollutant	Averaging Period	Air Concentrations (µg/m³)		
		Predicted	Limit	Fraction of Limit
PM10	Highest daily	14.4	150 (b, h) 100 (c) 75 (d, g) 50 (e, f)	0.10 0.14 0.19 0.29
	Annual average	2.0	70 (b) 50 (c, h) 40 (g) 30 (d, f) 20 (e, f)	0.03 0.04 0.05 0.07 0.10
SO_2	Highest hourly	13.6	350 (f)	0.04
	Highest daily	6.0	150 (h) 125 (b, f, g) 50 (c) 20 (e)	0.04 0.05 0.12 0.30
	Annual average	0.8	80 (8) 50 (g) 20 (f)	0.01 0.02 0.04
NO_2	Highest hourly	52.6	200 (e, f, g)	0.26
	Highest daily	23	150 (h)	0.15
	Annual average	3	100 (h) 40 (e, f, g)	0.03 0.08
CO	Highest hourly	19.6	30 000 (f)	<0.01

Notes:
(a) The IFC and World Bank Group state that in the absence of national legislated standards (as in the case of Namibia), the current WHO Air Quality Guidelines or other internationally recognised sources should be used.
(b)) WHO interim target-1.
(c) WHO interim target-2 (For SO_2 this interim target is stated as being a reasonable and feasible goal for developing countries).
(d) WHO interim target-3.
(e) WHO guideline value.
(f) EC directive.
(g) National Ambient Air Quality Standard..
(h) World Bank - Thermal Power: Guidelines for New Plants – Ambient Air Quality.

3.3.2 Radionuclides

(a) Source Terms

Radionuclide source terms[16] were obtained for Areva (EPR) and Westinghouse (AP1000) technologies to determine the envelope (i.e. worst-case) impact prediction.

[16] Small amounts of radionuclides are released during normal operation of the nuclear power station. Most of these emissions are, however, captured by High Efficiency Particulate Air filters, known as HEPA filters. HEPA filters, by definition, remove at least 99.97% of airborne particles 0.3 µm in diameter. The radionuclide emissions that still manage to find their way to the atmosphere include tritium, carbon-14, iodine isotopes, noble gases and a small amount of other fission/activation products (mainly cobalt and caesium). Noble gases typically include krypton, xenon and argon. These emissions are continuously monitored and reported to the NNR for compliance proposes.

These source terms are provided in Appendix B. The main source of gaseous radioactive emissions during normal operation is the gaseous component arising within the coolant circuit. These gases are collected by the gaseous radwaste system and held for decay storage in the activated carbon bed delay system. This delay system includes a gas cooler, a moisture separator, an activated carbon-filled guard bed, and two activated carbon-filled delay beds. The effluent from the delay bed passes through a radiation monitor and discharges to the ventilation exhaust duct. The gaseous radwaste system is used intermittently. Most of the time during normal operation of the reactors, the gaseous radwaste system is inactive. When there is no waste gas inflow to the system, a small nitrogen gas flow is injected into the discharge line at the inlet of the discharge isolation valve. This nitrogen gas flow maintains the gaseous radwaste system at a positive pressure, preventing the ingress of air during periods of low waste gas flow.

Gaseous activity will also be present in the main process buildings, which are serviced by the heating, ventilation and air-conditioning (HVAC) systems. Discharges from these systems are via high level stacks located on the top of the reactor building and the radwaste building. There is provision for monitoring these discharges after filtration through high efficiency particulate air (HEPA) filters and, where appropriate, charcoal adsorption. There is also the possibility of tritium in the secondary circuit from minor leaks from the primary circuit. This is collected in the condenser air removal system. There would be provisions for sampling and monitoring gaseous effluents at various points in the gaseous radwaste system.

The Appendix also includes source terms for Koeberg, as reported to the NNR and an estimated worse-case source term for the proposed PBMR DPP.

These given source terms provided no information on the exact chemical forms. All emissions were therefore simulated as gases. This assumption allows for a more conservative air concentration estimate. On the other hand, fallout of particulates is important for deposition rates and this may be under-estimated if the correct particle size distributions are not used. The dry and wet deposition rate models internal to the AERMOD model were used in the assessment. These models incorporate land use information as well as atmospheric stability. Using the air concentration and deposition rate results from the AEMOD model, the calculated deposition velocity varies between 0.018 m/s to 0.33 m/s. This is fairly conservative when considering typical dry deposition velocities for radionuclides of 0.0004 m/s (^{137}Cs) and 0.003 m/s (^{131}I) [Roed (1987) and Nicholson (1987)].

(b) Predicted Doses

The methodology described in IAEA Safety Report No. 19 (IAEA 2001) was adopted in the estimation of inhalation and immersion dose. The first step in this approach is to estimate the nature and magnitude of the proposed discharge of radioactive material into the environment (Appendix B). The transport of materials discharged to the atmosphere system is modelled and the concentration distribution of radionuclides in the study area of 40 km by 40 km is assessed. The model is designed to estimate the maximum annual dose received during the period of the practice. The inventory of long lived radionuclides builds up in the environment, with the result that exposures may increase as the discharge continues. For screening modelling purposes the maximum annual dose was assumed to be the dose that would be received in a discharge period of 30 years. In the absence of any better knowledge, the emission rates were kept constant for this 30-year period.

Therefore with the given discharge rates (source terms) in Appendix B, the next step in the procedure is to estimate the relevant annual average radionuclide concentration in air. The AERMOD atmospheric dispersion model (see Section 1.2.3) was used to estimate annual average radionuclide concentrations in air and the annual average rate of deposition.

The calculated average radionuclide concentrations in air (Bq/m³) is then combined with the annual inhalation rates of intake (m³/annum) to obtain an estimate of the total radionuclide intake during a year (Bq/annum). Inhalation rates change substantially due to a variety of factors, which include age, weight, health, and activity level. The goal here was to be conservative and therefore used the maximum inhalation rate (i.e. 23 m³/day) appropriate for application to annual average values of airborne concentrations. This total intake over the year is then multiplied by the appropriate Dose Conversion Coefficient ICRP (1996) in Sv/Bq to obtain an estimate of the maximum effective dose (Sv/annum) in one year from inhalation. ICRP 72 ICRP (1996) is a summary of data on age-dependent committed effective dose coefficients for members of the public from intakes by ingestion and inhalation of radioisotopes of the 91 elements described in ICRP Publications 56, 67, 68, 69 and 71. These dose coefficients have been adopted in the International Atomic Energy Agency in their publication on International Basic Safety Standards for Protection against Ionising Radiation, and in the Euratom Directive. In all cases, the assessment adopted the highest Dose Conversion Coefficients.

In a similar manner, the concentrations of radionuclides in surface soils in the 30th year of discharge are used with appropriate dose coefficients to estimate the effective dose received during that year from external irradiation. The effective dose in one year from immersion in a cloud containing radionuclides may be calculated by multiplying the average concentration in air by the appropriate external dose coefficients. The total maximum effective dose in one year (representative of the 30th year of discharge) due to inhalation and immersion is obtained by summing the effective doses from inhalation, cloud immersion and ground radiation.

The predicted maximum effective dose (inhalation and external) for Duynefontein is given in Figure 3-12. The predicted maximum effective doses for Bantamsklip and Thyspunt are given in Figure 3-16 and Figure 3-20, respectively.

The model-wide maximum predictions for the three sites are summarised in Table 3-12.

Table 3-12: Maximum inhalation and external effective dose predicted in the 40 km by 40 km study area for 4000 MWe nuclear power station

Site	Effective Dose (µSv/annum)
Duynefontein	4.07
Bantamsklip	4.60
Thyspunt	11.31

Government Notice No. R 388 of 2006 specifies that the annual effective dose limit for members of the public from all authorised actions is 1 000 µSv (Appendix A) with an additional provision of an annual dose constraint of 250 µSv. The highest predicted inhalation and external effective dose of 11.3 µSv is therefore about 4.5% of the dose constraint and about 1% of the annual effective dose limit. With the addition of more units to eventually generate 10 000 MWe, the maximum external effective dose would be less than 30 µSv.

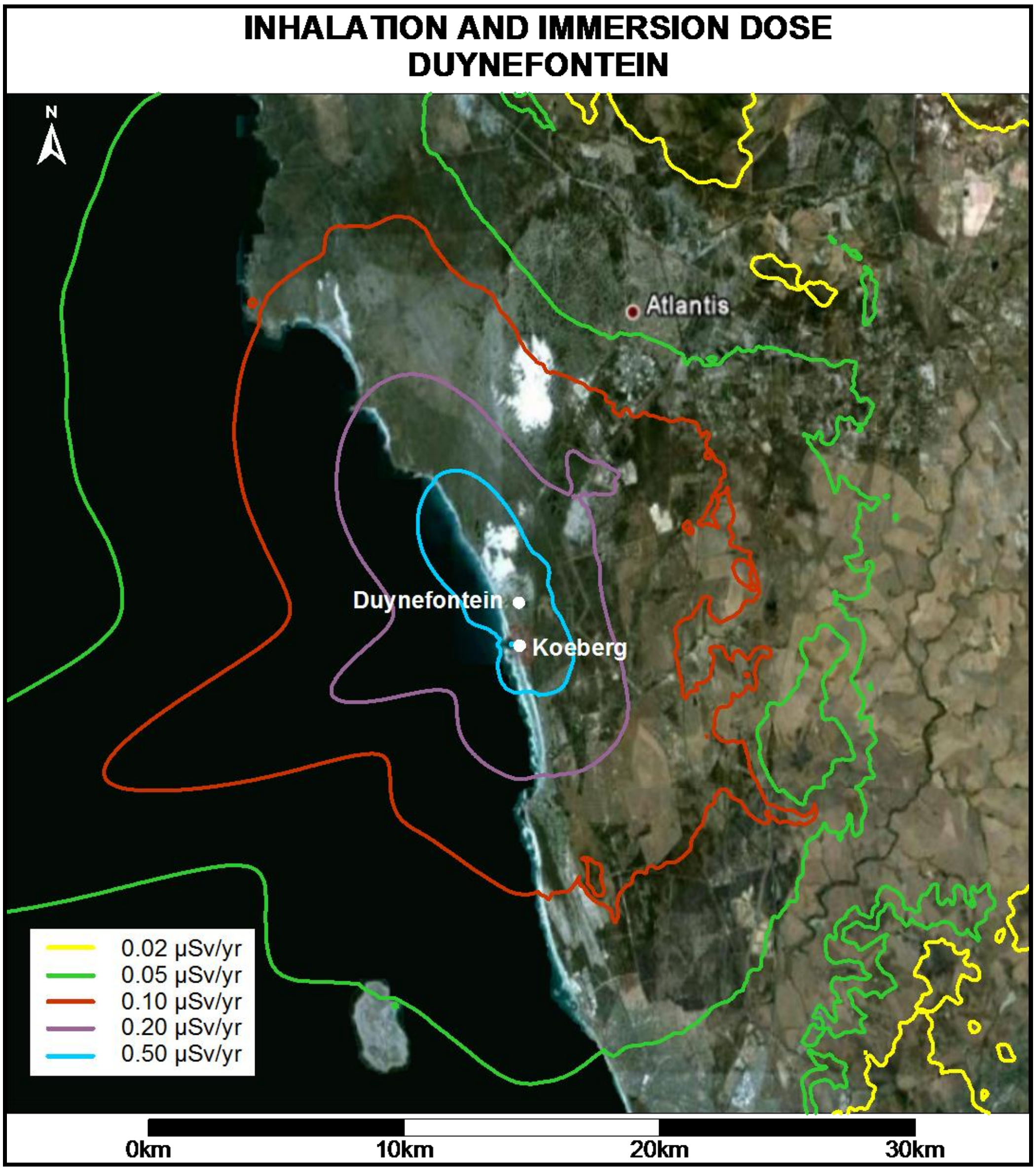


Figure 3-12: Predicted maximum cumulative annual inhalation and external radiation dose (µSv) for Duynefontein using 30 year equilibrium for deposition

The predicted annual average cumulative activities at Duynefontein for strontium-90, iodine-131 and cesium-137 are given in provided Figure 3-13, Figure 3-14 and Figure 3-15, respectively.

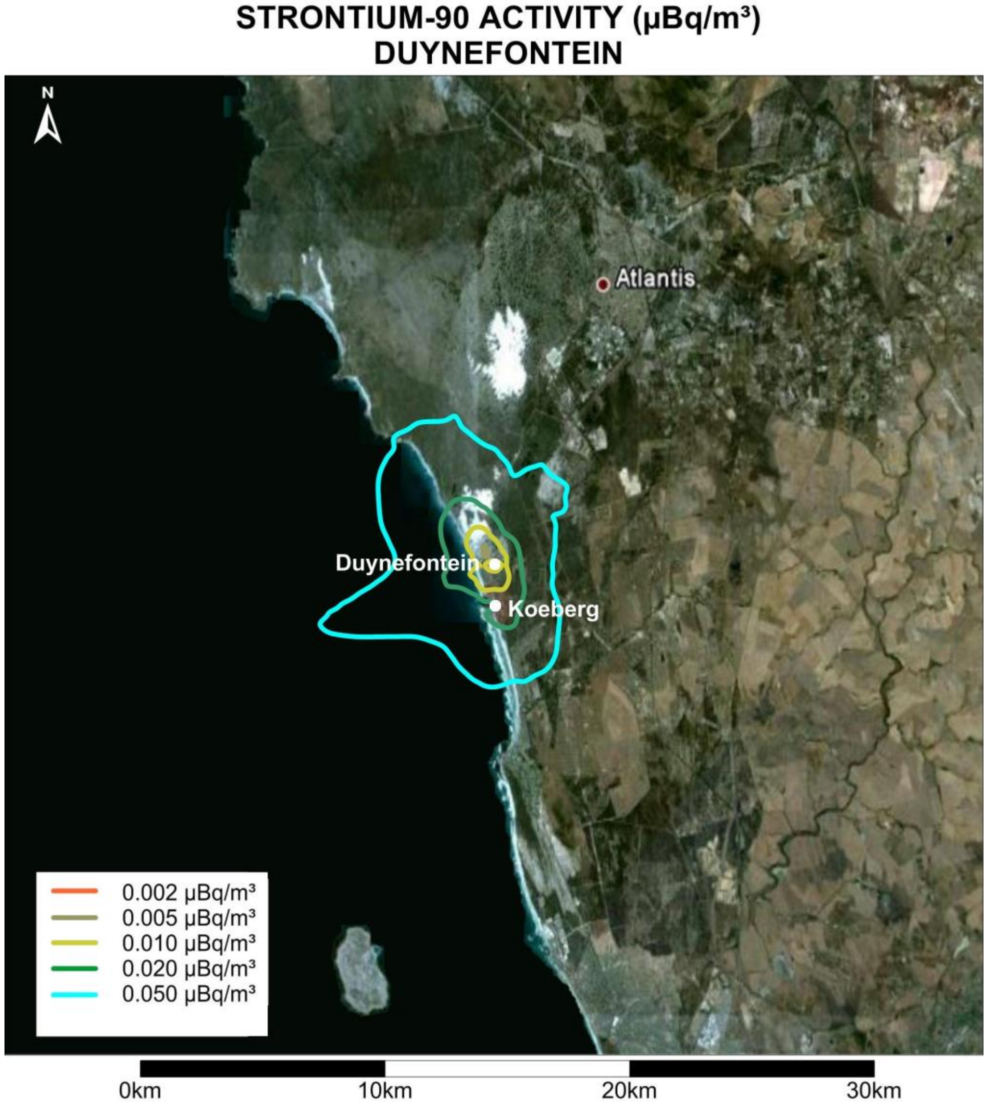


Figure 3-13: Predicted maximum cumulative annual Strontium-90 activity envelope (µBq/m³) for Duynefontein

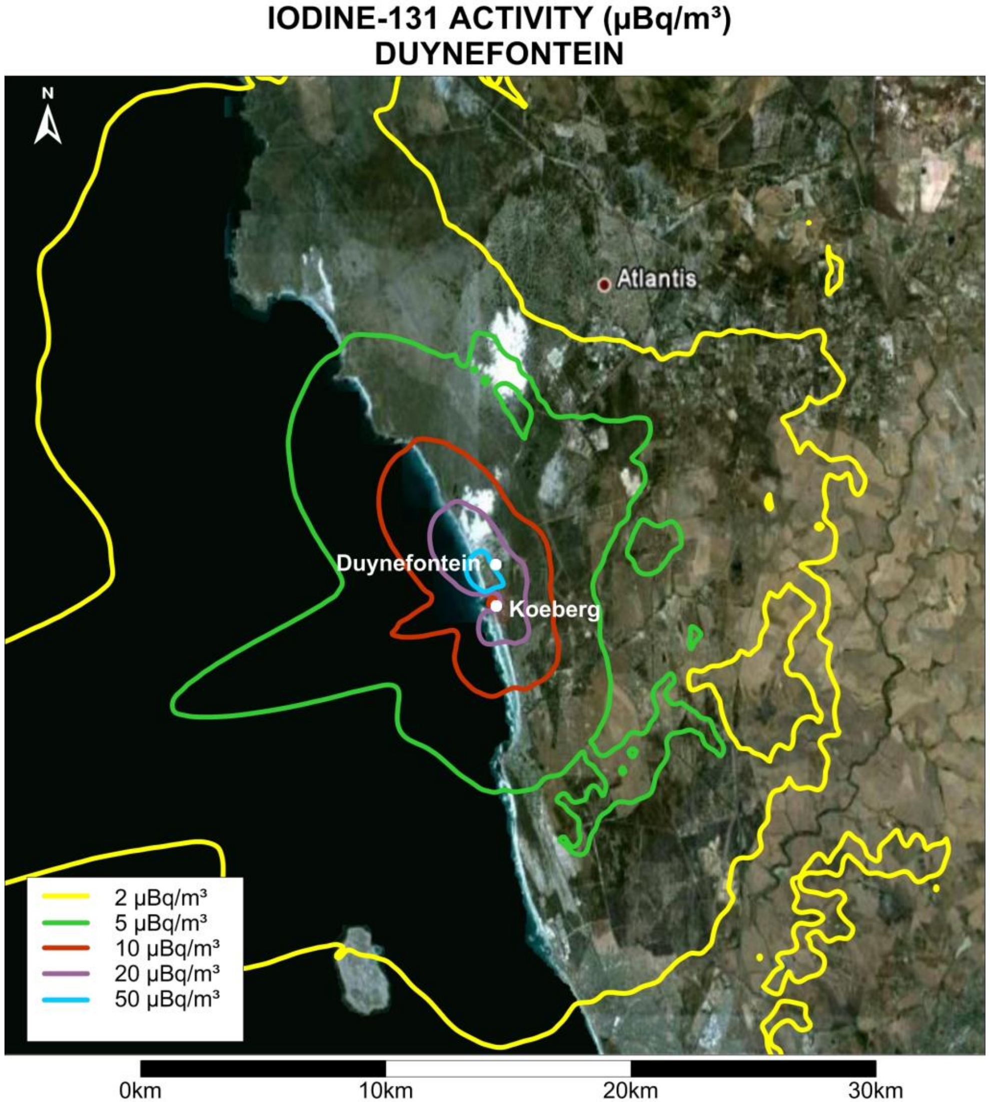


Figure 3-14: Predicted maximum cumulative annual Iodine-131 activity envelope (µBq/m³) for Duynefontein

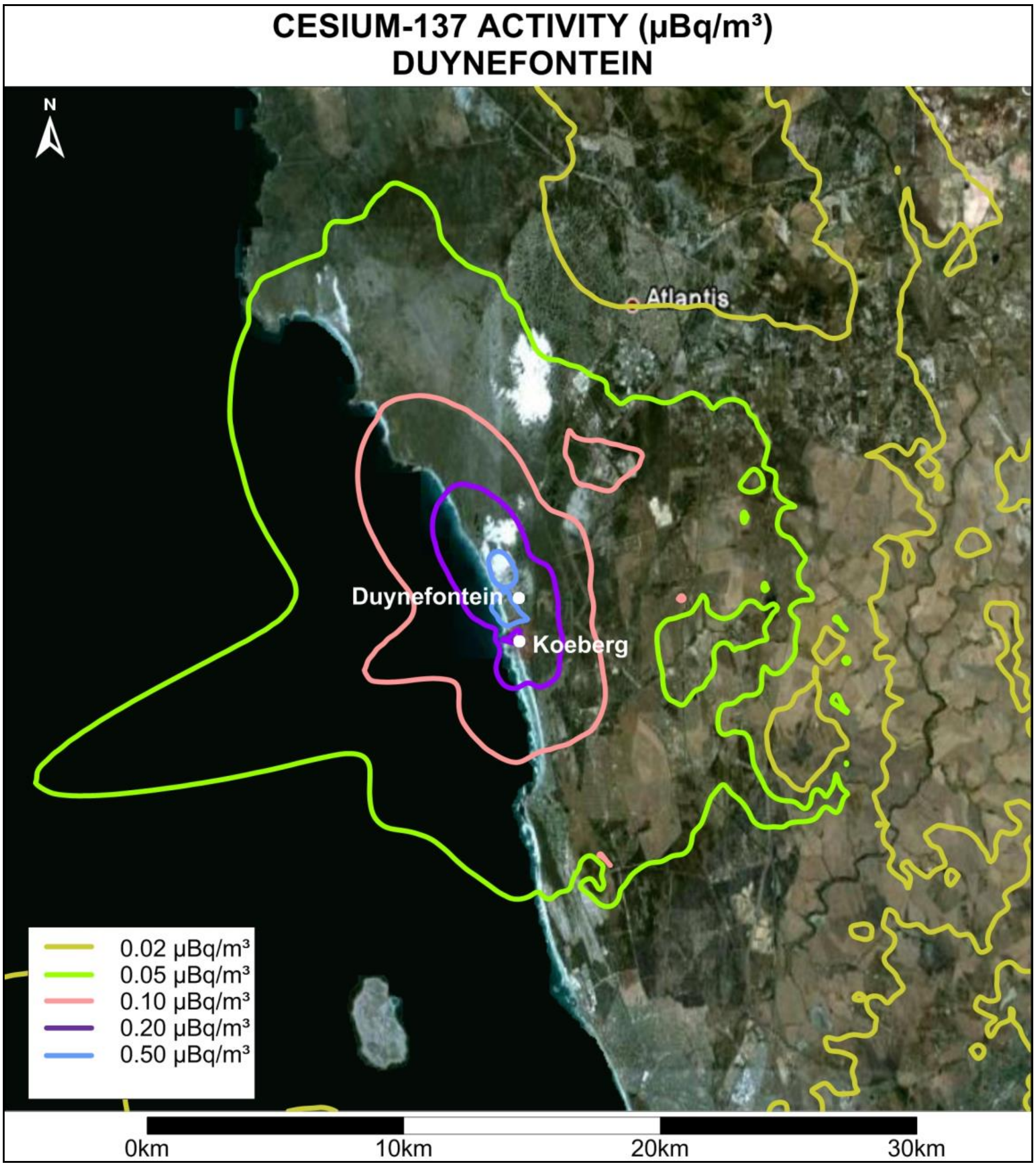


Figure 3-15: Predicted maximum cumulative annual Cesium-137 activity envelope (µBq/m³) for Duynefontein

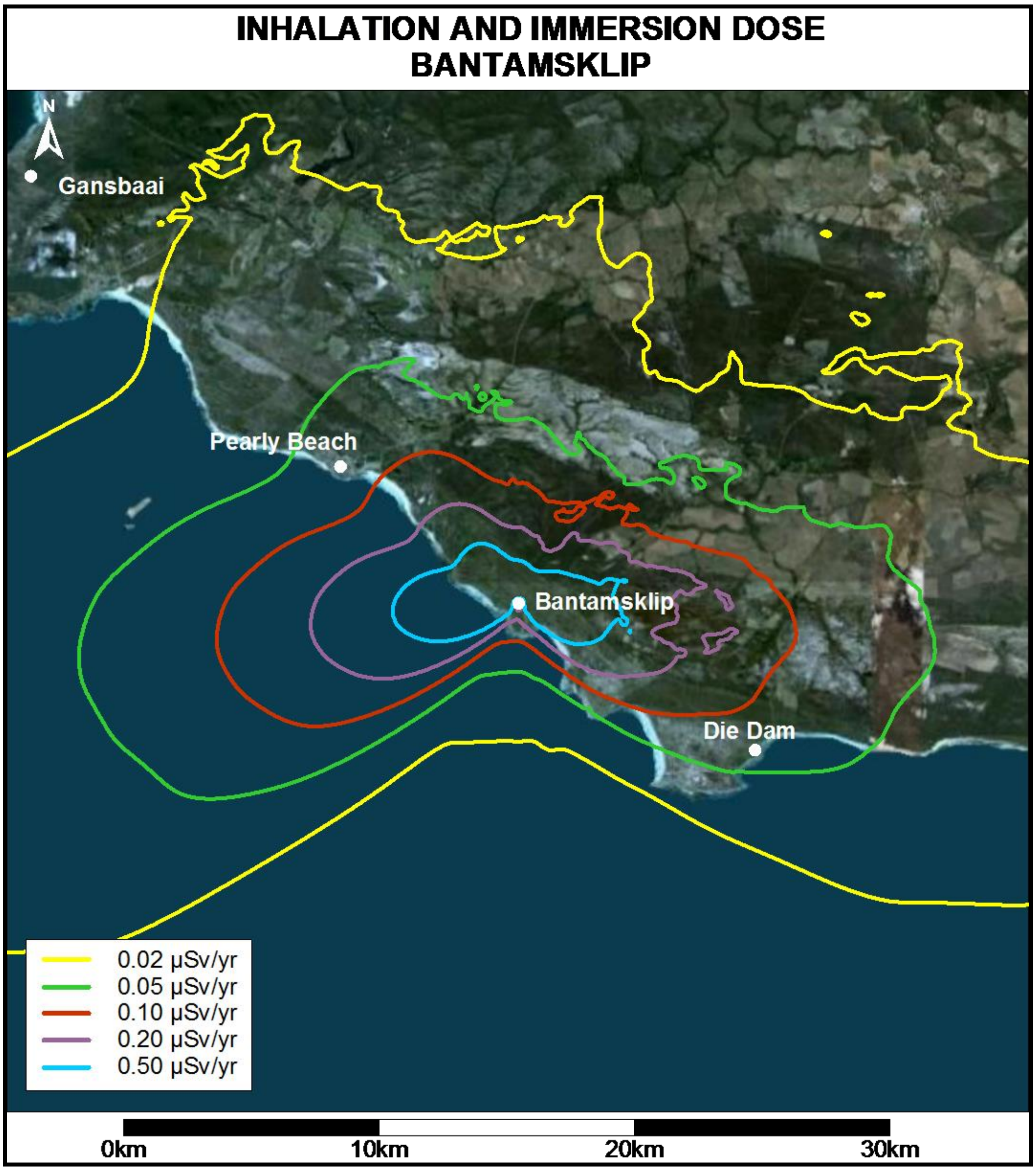


Figure 3-16: Predicted maximum cumulative annual inhalation and external radiation dose (µSv) for Bantamsklip using 30 year equilibrium for deposition

The predicted annual average activities at Bantamsklip for strontium-90, iodine-131 and cesium-137 are given in provided Figure 3-17, Figure 3-18 and Figure 3-19, respectively.

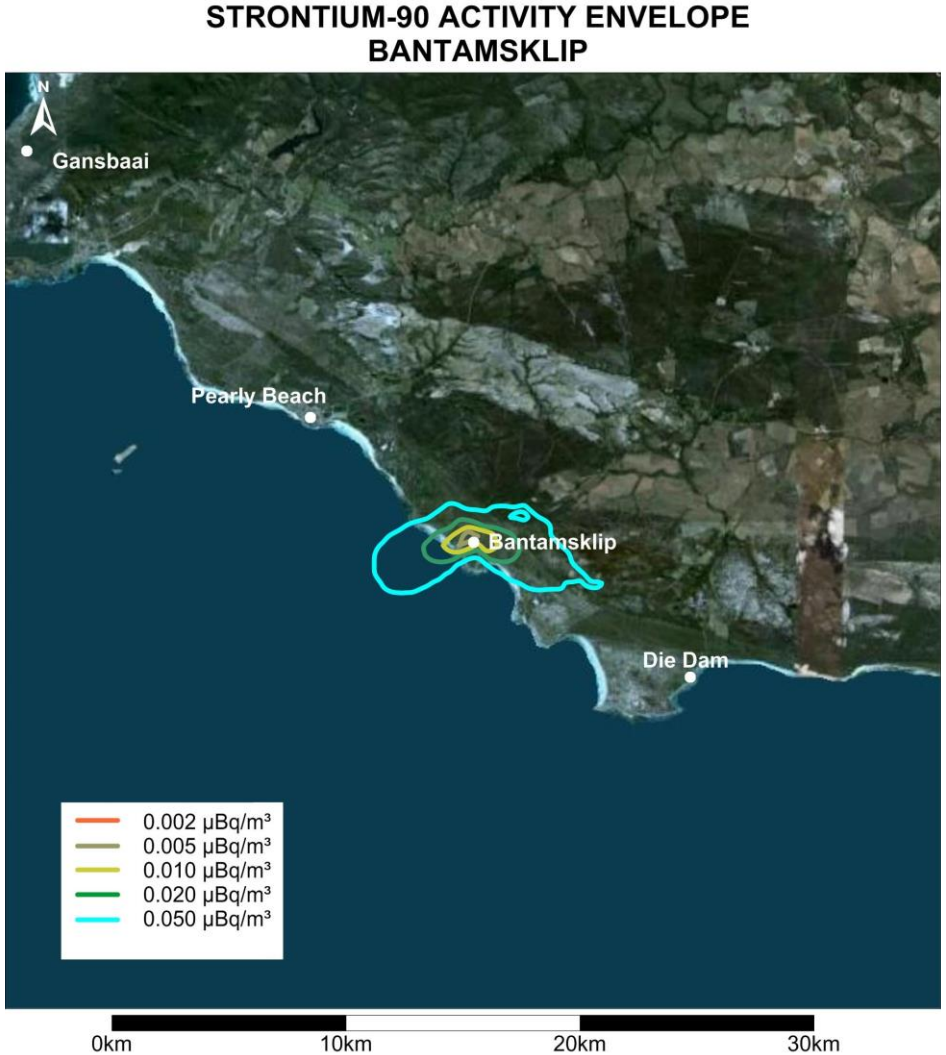


Figure 3-17: Predicted maximum cumulative annual Strontium-90 activity envelope (µBq/m³) for Bantamsklip

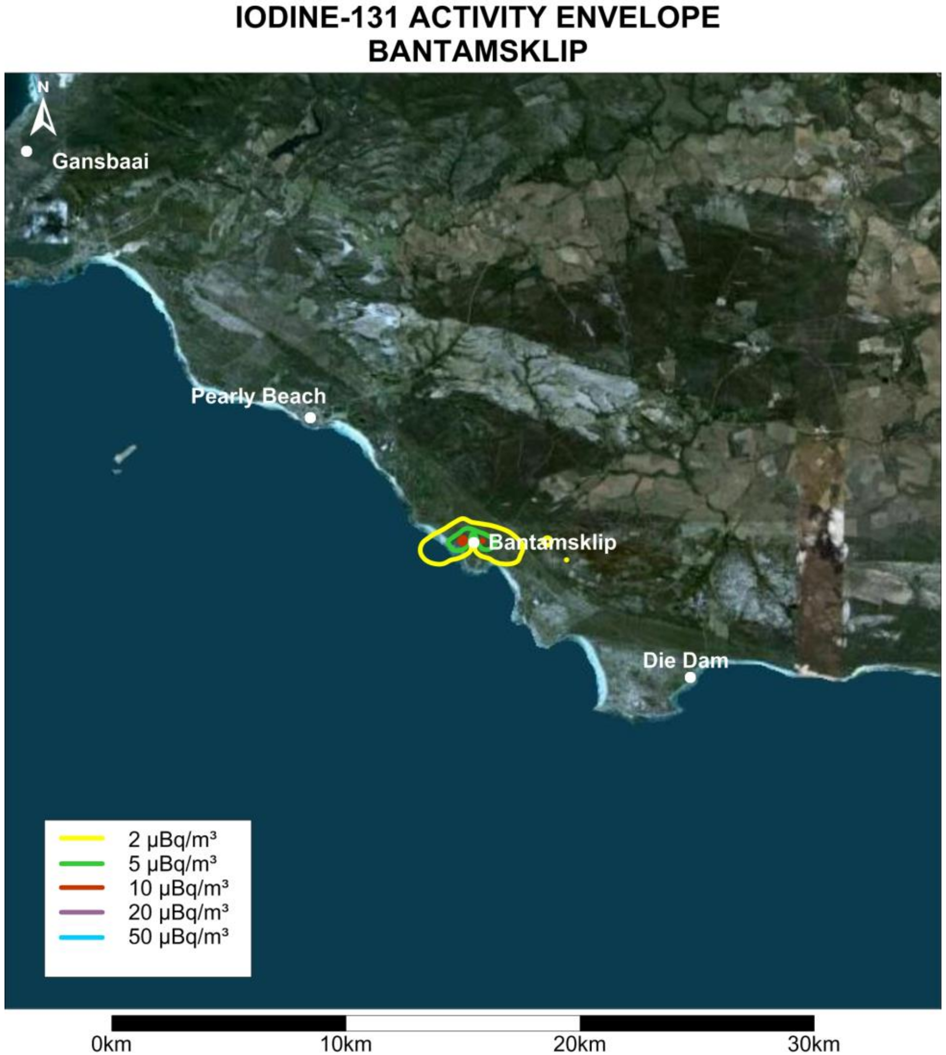


Figure 3-18: Predicted maximum cumulative annual Iodine-131 activity envelope (µBq/m³) for Bantamsklip

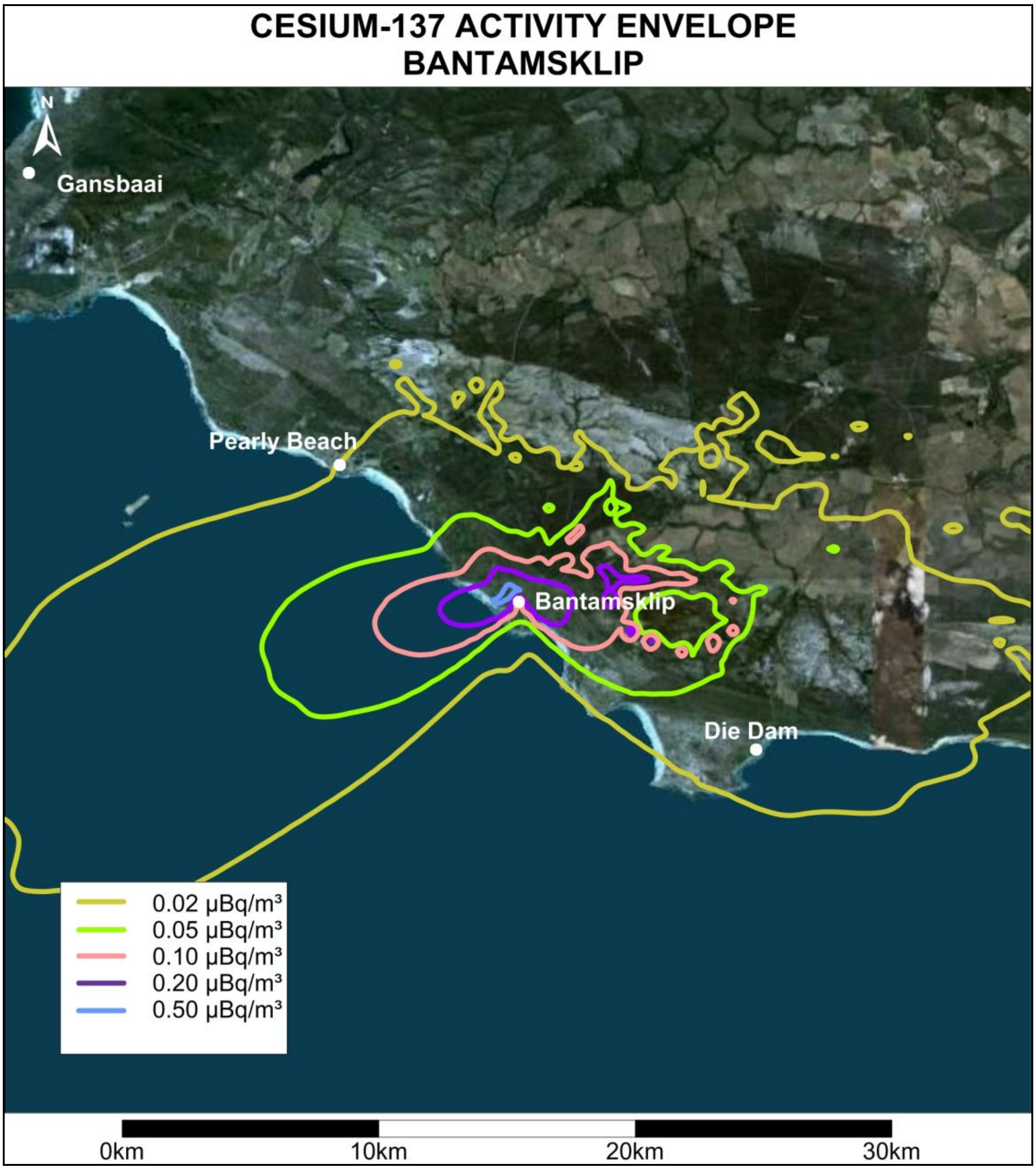


Figure 3-19: Predicted maximum cumulative annual Cesium-137 activity envelope (µBq/m³) for Bantamsklip

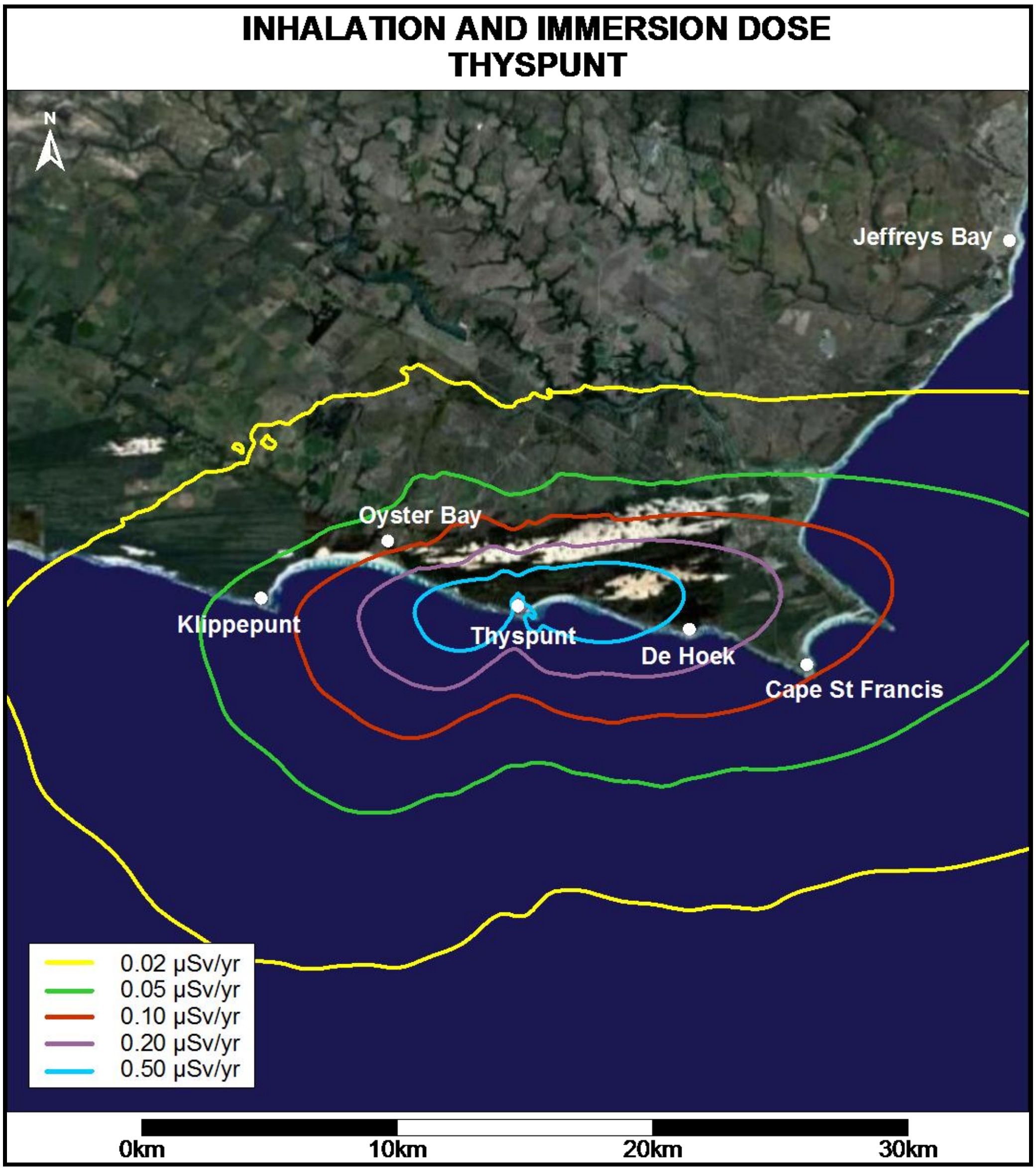


Figure 3-20: Predicted maximum cumulative annual inhalation and external radiation dose (µSv) for Thyspunt using 30 year equilibrium for deposition

The predicted annual average activities at Thyspunt for strontium-90, iodine-131 and cesium-137 are given in provided Figure 3-21, Figure 3-22 and Figure 3-23, respectively.

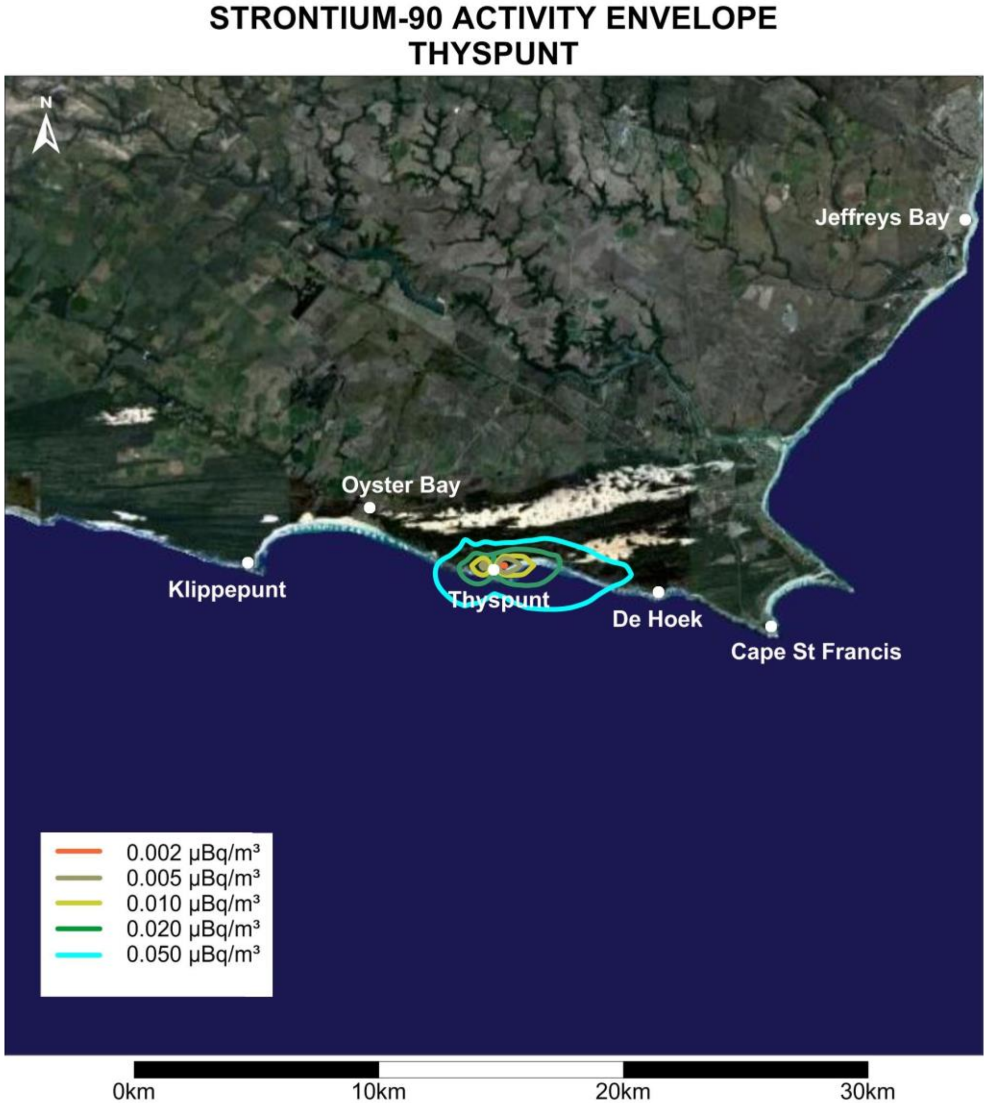


Figure 3-21: Predicted maximum cumulative annual Strontium-90 activity envelope (µBq/m³) for Thyspunt

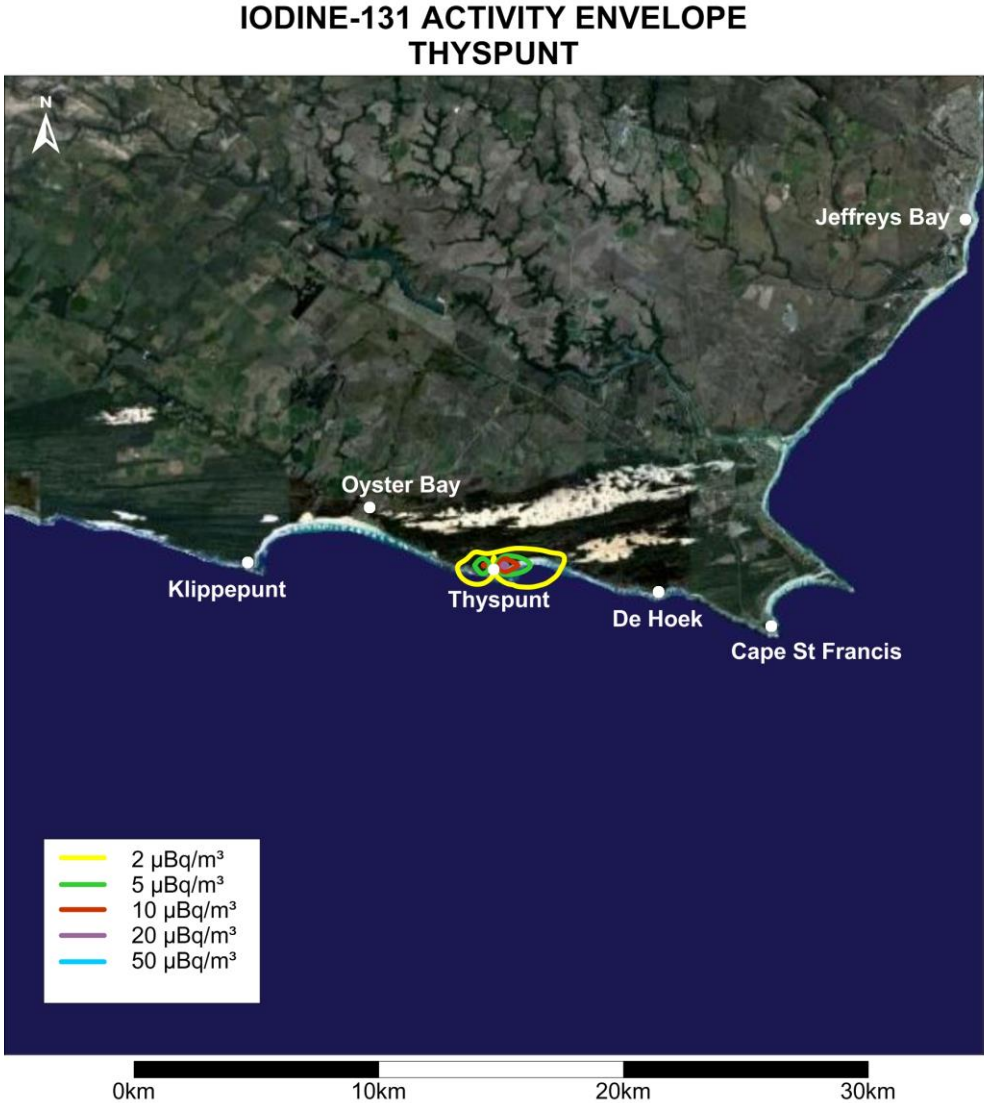


Figure 3-22: Predicted maximum cumulative annual Iodine-131 activity envelope (µBq/m³) for Thyspunt

CESIUM-137 ACTIVITY ENVELOPE
THYSPUNT

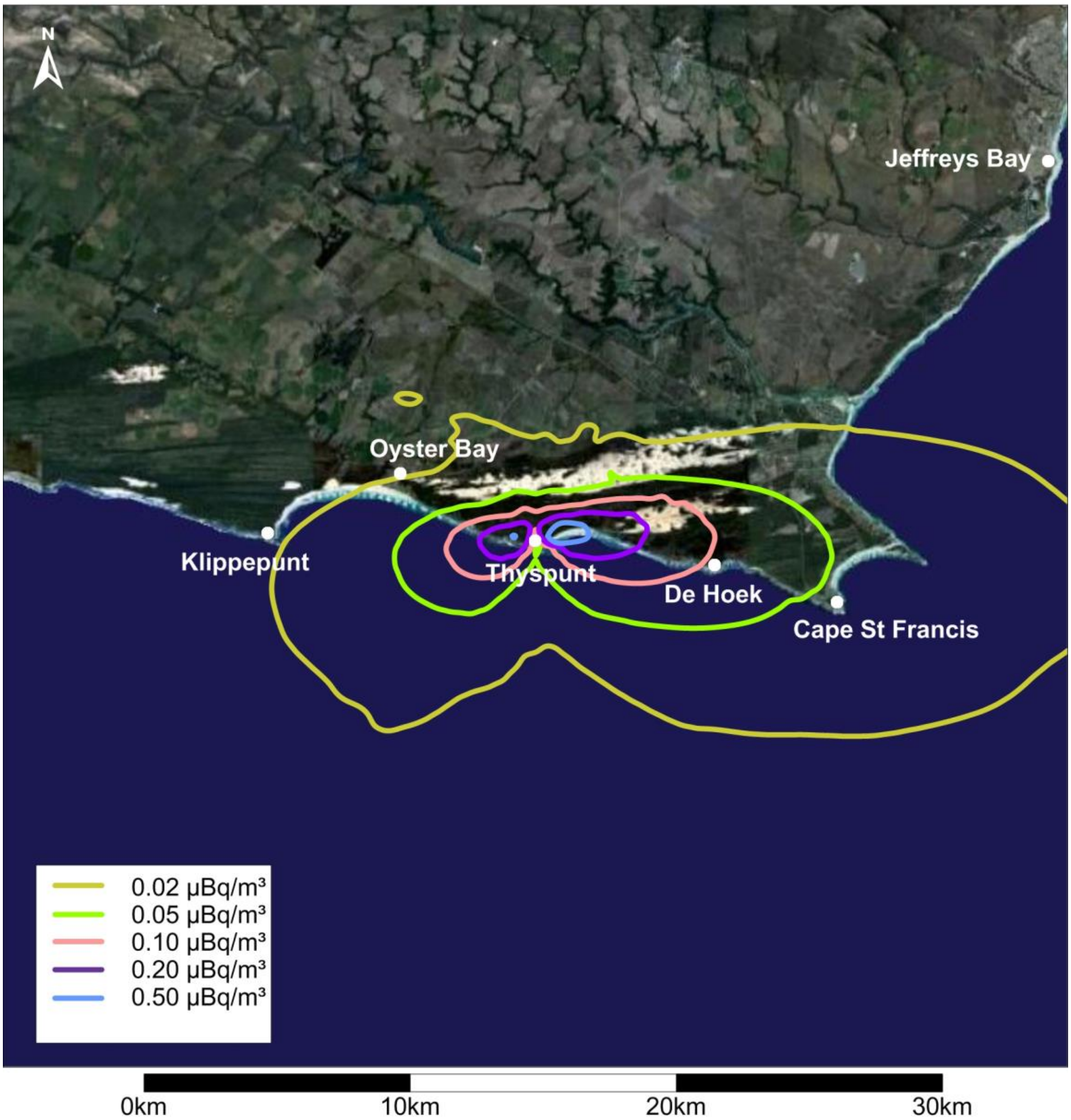


Figure 3-23: Predicted maximum cumulative annual Cesium-137 activity envelope (µBq/m³) for Thyspunt

(c) Design Basis Accident Releases

The nuclear power station must be designed and built to withstand a number of postulated accidents without loss to the systems, structures, and components necessary to assure public health and safety. Catastrophic incidents were not part of the plan of study for the assessment since these incidents are within the jurisdiction and mandate of the NNR. The NNR will evaluate the safety case for the proposed nuclear power station to determine compliance with the requirements contained in Government Notice R388 of 28 April 2006, “Safety Standards and Regulatory Practices”. The NNR process has not start yet, but will follow after the specific PWR vendor has been selected as part of the procurement process.

Although accident scenarios have not been expressly dealt with in this assessment, a number of typical Design Basis Accidents (DBAs) for PWR technologies were included to provide a screening level assessment. DBAs could include pipe ruptures, component failures, etc. which must be controlled by the safety facilities in such a way that effects on the environment are kept below the specified planning values of the NNR; i.e. the effective dose to a worker or members of the public is less than 50 mSv. Actual DBAs can only be determined once the vendor and, hence, the plant is known. The DBA releases used in the assessment are described further in Appendix B. The predicted maximum ground level air concentration levels for each of the anticipated radio-nuclides per DBA were calculated at increasing downwind conditions. The maximum effective dose per DBA was subsequently calculated using the most conservative Dose Conversion Coefficient (ICRP, 1996) for inhalation. The results have been provided for inclusion in the Health Risk Assessment.

Assuming the DBA releases to be at ground level (worst-case scenario), the highest whole body dose at 1 km downwind from the nuclear power station at Thyspunt was predicted to be 49 mSv. At 2 km downwind from the nuclear power station the predicted whole body dose was 20 mSv. Similarly, at 5 km, the highest whole body dose was predicted to be 8 mSv, 3.8 mSv at 10 km and 1.0 mSv at 20 km, respectively. These doses are within the maximum allowable public dose of 50 mSv applicable to accidental releases. Similar values were obtained for Bantamsklip and Duynefontein.

It must be emphasised that whilst it is believed that this assessment has provided a realistically conservative envelope of DBA impacts, a proper evaluation of DBAs can only be completed once the actual reactor design has been selected. These impacts are shown to be within the NNR requirement of 50 mSv. Long-range concentrations will therefore be significantly less.

(d) Long-Range Trajectories

The terms of reference required that long-range trajectories be included in the investigation. The long-range trajectories and dispersion of emissions from the proposed nuclear power station was simulated using the Hysplit long-range dispersion model. The plume centreline is illustrated by the trajectory paths in the figures. These trajectories provide the location of the plume at increasing time intervals after release.

In the following sections dominant weather events that influence the Western Cape and southern coast line are discussed. Although these events date back to the 1979s, nothing has changed and they still occur today. The reason why 1979 events were chosen is because these events are examples from a text book on weather events of South Africa (Van Heerden and Hurry, 1987).

The lines on the maps below should be interpreted as follows:

Dotted lines over the ocean	:	Sea level pressures (hPa)
Solid lines over the continent	:	heights of the 850 hPa pressure level
Solid lines over ocean and continent	:	heights of the 500 hPa pressure level

Note that flow is clockwise around lower pressure systems and counter-clockwise around higher pressure systems.

(i) EVENT 1: Calm Winter Situation

During a typical winter day, high pressures dominate on the surface as well in the upper atmosphere (Figure 3-24). Such conditions will limit vertical mixing, meaning that pollutants are trapped in the lower parts of the atmosphere (near the surface). Higher latitude cyclones to the south will allow for a relatively steep north-south pressure gradient to the south of the country, which might result in strong winds to the south. However, pressure gradients are weak over the interior with little or no wind. Reduced surface radiation will result in cold conditions. These conditions are typical mid-latitude high pressure conditions where continental interference is minimal.

The predicted paths for a calm winter situation are summarised in Figure 3-25. The plot illustrates the locations of the plume released, in this instance, from the Duynefontein site, for the period 27, 28 and 29 June 1979. Each trajectory represents a release on a 6-hourly interval.

The trajectories indicate that particle transport takes place over the ocean and along the southern coastline. This is mainly because of calm conditions over land and a zonal pressure gradient to the south. At the beginning transport takes place from west to east, which is what is expected from the weather map of 28 June 1979. Vertical mixing is generally limited, meaning that particles will mostly move close to the Earth's surface.

(ii) EVENT 2: Left Hook System

A typical left hook system is associated with the development of a west to east propagation of a strong, low pressure system (cyclone) over the ocean to the south of the continent (Figure 3-26).

Such systems normally develop during winter months when mid-latitude cyclones are stronger and deeper. The clockwise rotation around such a cyclone will result in strong winds from the west and south west (from there the name left hook). These winds will propagate cold air from far south over the country, as indicated on the weather map. Because of steep pressure gradients accompanied by strong winds, these systems might cause high ocean swells, and possible structural damage along the coastlines. In recent years a number of these systems were responsible for gale force winds, high swells and damage over the coastal areas. Since winter months do not bring rain over the summer rainfall region, strong winds over the interior might hold a fire risk which might develop in runaway fires which are difficult to control.

The initial trajectories (Figure 3-27) coincided with a strong cyclone approaching the southern coast line, which allow for transportation towards the south eastern ocean. As the cyclone moves to position itself to the south of the continent, trajectories change northwards to propagate the particles deep over the interior. This is also shown clearly in Figure 3-28, which includes the trajectories on 11 June 1979 for all three sites. Although separated spatially, the trajectory from Bantamsklip shows a similar pattern as the release from Duynefontein, indicating that a similar air flow system was responsible for the transport of the emissions from the two locations. However, these conditions would not have reached the Thyspunt site until a few hours later. Figure 3-29 illustrates the trajectories on 12 June 1979, clearly showing the arrival of the left hook system at Thyspunt. This figure also illustrates all three trajectories to advect towards the west, as the cyclone propagates eastward.

A left hook system normally results in stable cold conditions over land, which will reduce vertical mixing of particles.

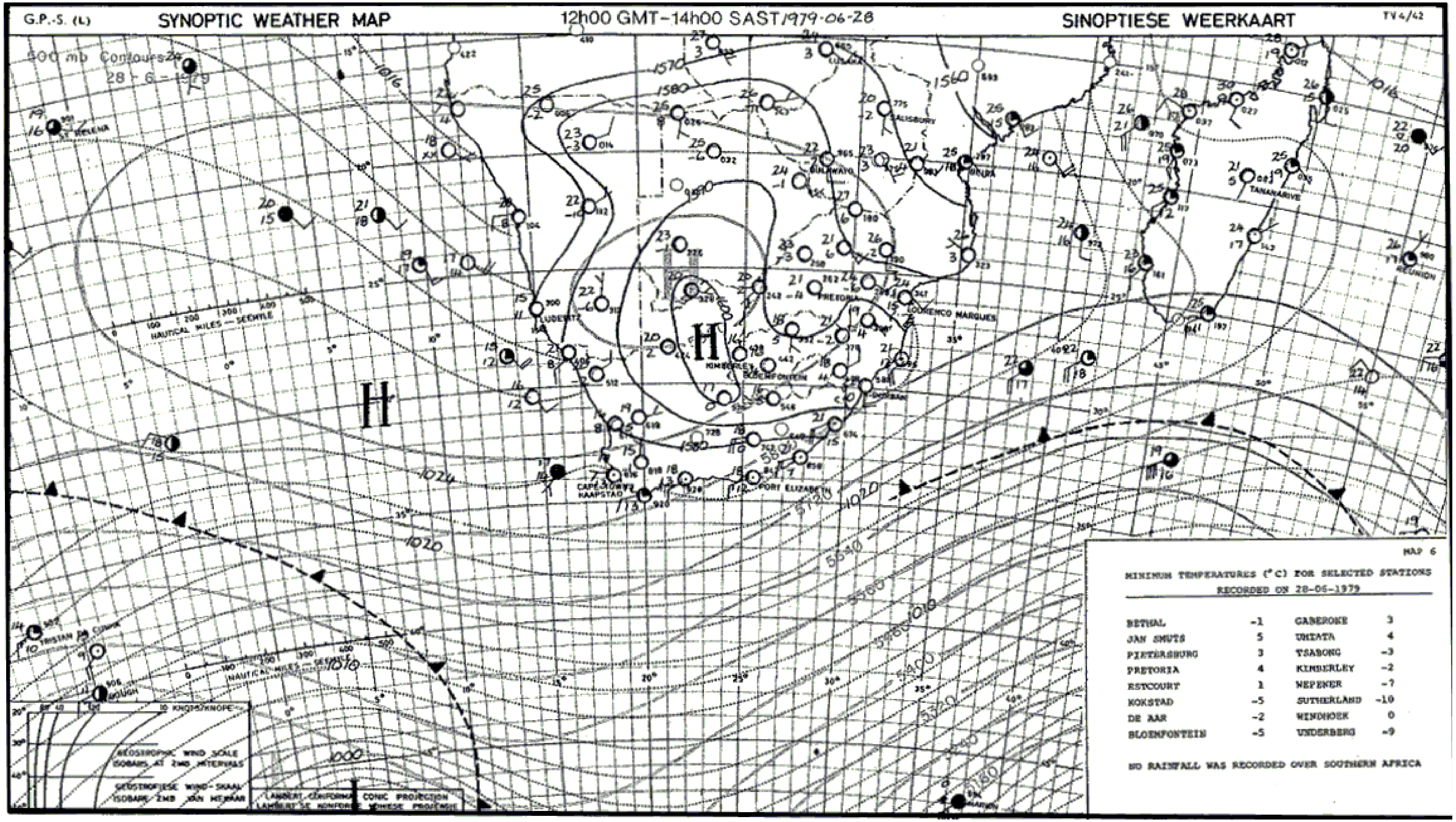


Figure 3-24: Calm winter situation (28 June 1979)

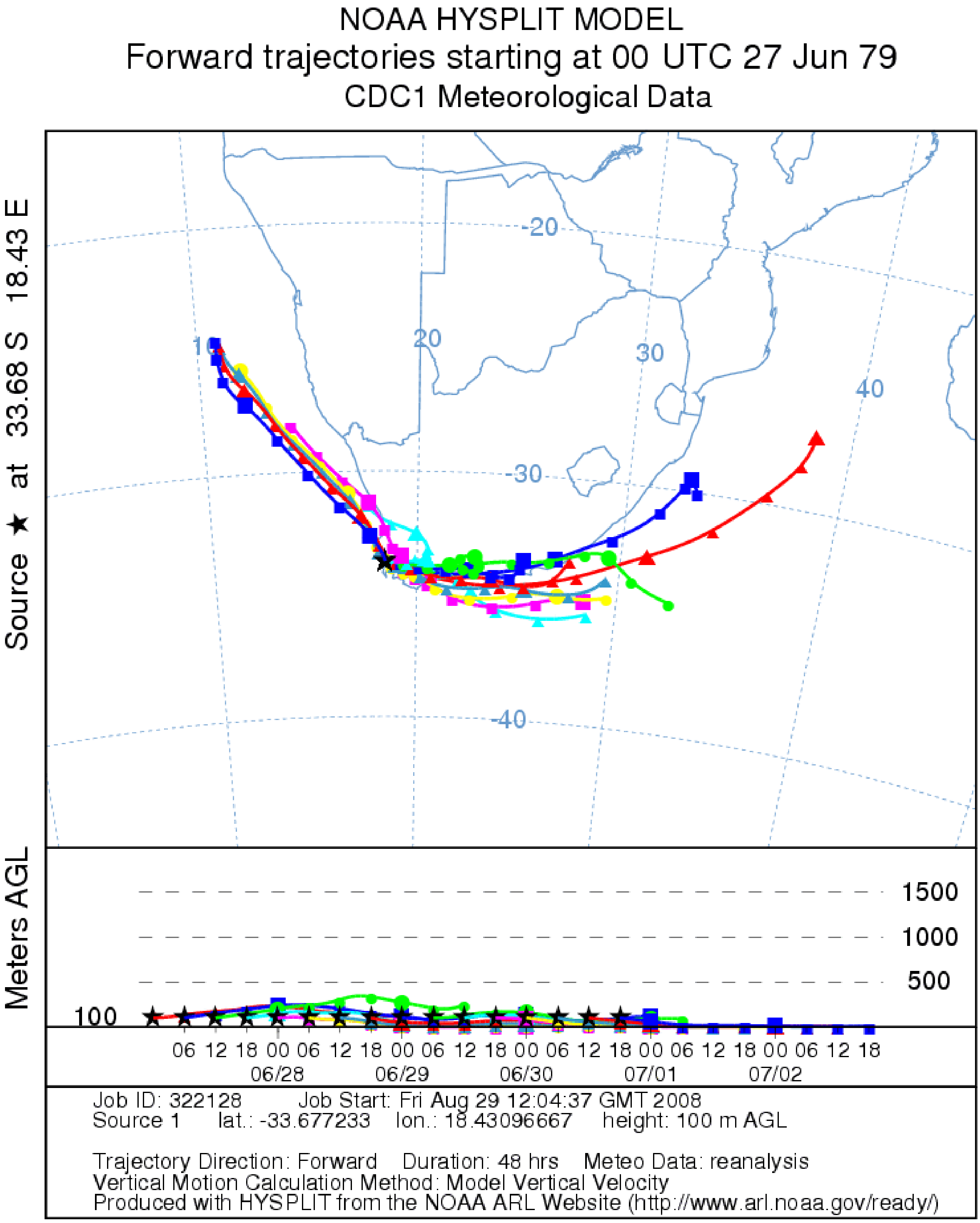


Figure 3-25: Predicted trajectories emitted from Duynefontein site during a calm winter situation, as described in Figure 3-24. The different curves represent the trajectory at hourly intervals, with the first 16 hours being represented here. The starting point of each trajectory is indicated in the lower graph with a star.

(iii) EVENT 3: Cold Front over the Western Cape

Cold fronts are heavy cold polar air masses that propagate north and eastwards to restore the energy balance of the planetary atmosphere (Figure 3-30). Cold fronts could either sweep over the southern coastline or ocean of South Africa or penetrate the interior to bring typical cold winter conditions. These heavy air masses also serve as an obstacle against which warmer air might rise to form clouds and rain. A passing cold front is mostly associated with rain over the Western Cape and southern coast line region. Winds are predominantly from the north-west when a cold front approaches, but quickly change towards south-westerlies when the cold front passes. These winds might be strong if pressure and temperature gradients are steep.

As the cold front crosses over the western Cape, south-westerly winds allow for particle transport to be directed over the continent, from where, with the release from Duynefontein, it is redirected westwards over the ocean by the counter clockwise flow around the continental high (Figure 3-31). A cold front is normally followed by a high pressure system, and with counter clockwise rotation, this will result in trajectories far over the Atlantic Ocean. Since warmer air rises against the cold air mass from the south at the intersection of these two air masses (front line), vertical mixing will take place in the vicinity of the front.

The Bantamsklip trajectory displays a very similar flow pattern as for Duynefontein. The Thyspunt trajectory reflects the conditions prior to the arrival of the frontal system, and travels relatively far north and along the east coast. The western turn is only realised the following day (7 May, see Figure 3-33). At this stage, plumes from Duynefontein and Bantamsklip extend far over the Atlantic Ocean.

(iv) EVENT 4: Berg Winds over the Southern Coastline.

In the event of convection, air cools adiabatically[17]. If this cooling is sufficient, condensation will take place and rain will form. The opposite is also true. When air sinks, compression takes place and adiabatic heating will take place. At the same time the air will dry out. A berg wind is a typical example of air that subsides against the slopes of mountains and heats adiabatically. This normally happens when a surface high pressure system develops over the eastern parts of the country, as shown inFigure 3-34. This condition causes a counter-clockwise rotation, allowing for offshore flow over the Western Cape and southern coastline of South Africa. Steep pressure gradients might lead to strong subsidence and rapid heating, which might also lead to uncomfortably high temperatures and dry air. Berg winds, whether they occur along the south or east coast, always pose a fire risk.

Since berg winds are associated with offshore flow, trajectories will always point towards the ocean, away from the continent. This is clearly shown in all trajectory examples: Figure 3-35 (trajectories from Duynefontein site for days 2, 3 and 4 July 1979), Figure 3-36 (trajectories from all three sites for 3 July 1979) and Figure 3-37 (trajectories from all three sites for 4 July 1979).

[17] The term "adiabatic" literally means impassable, which in this context means an absence of heat transfer from a parcel of air to its surroundings, and therefore implies a change in temperature of the parcel of air without gain or loss of heat from outside the air parcel. Adiabatic cooling occurs due to the decrease in air pressure.

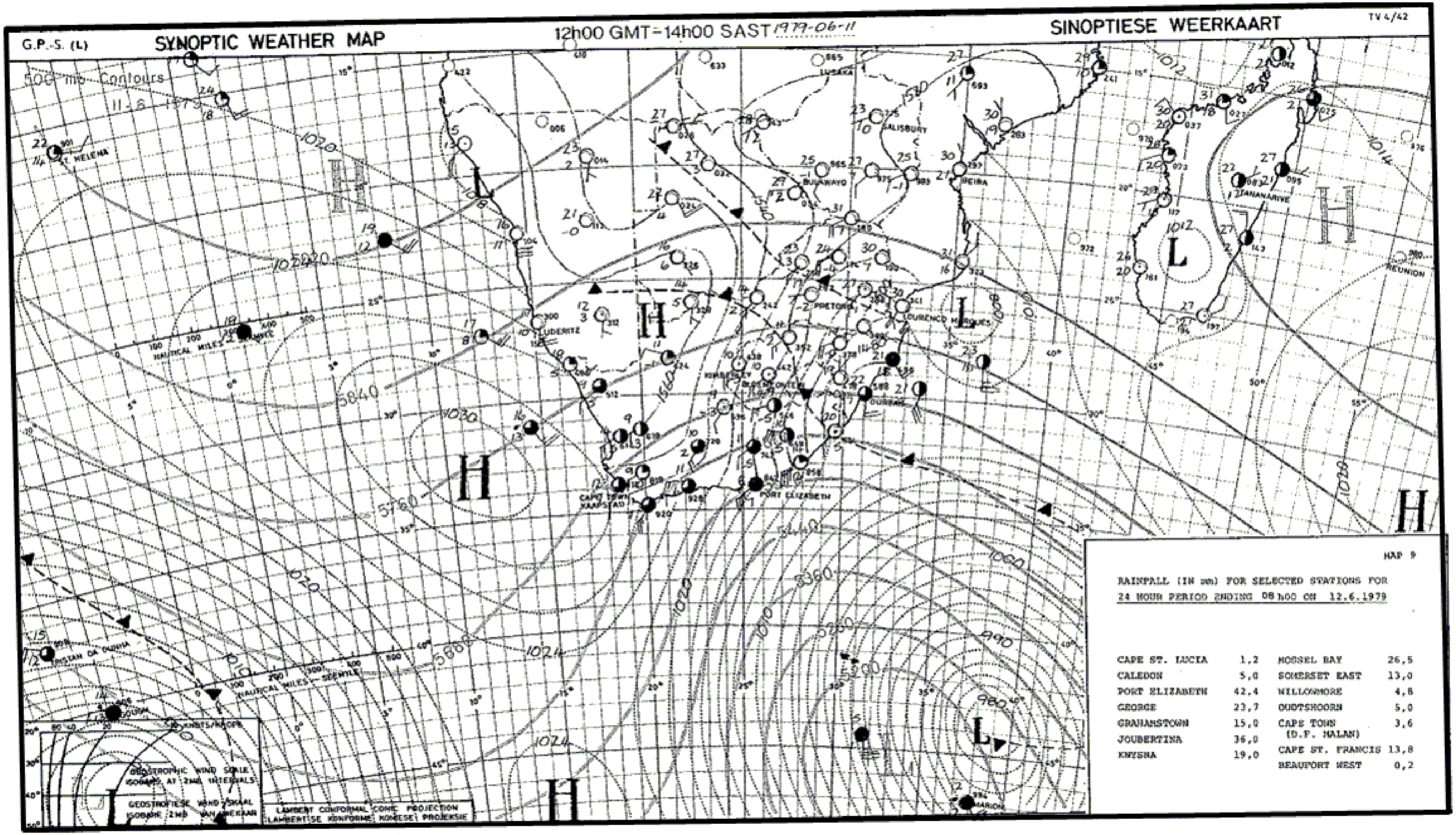


Figure 3-26: Left hook (11 June 1979)

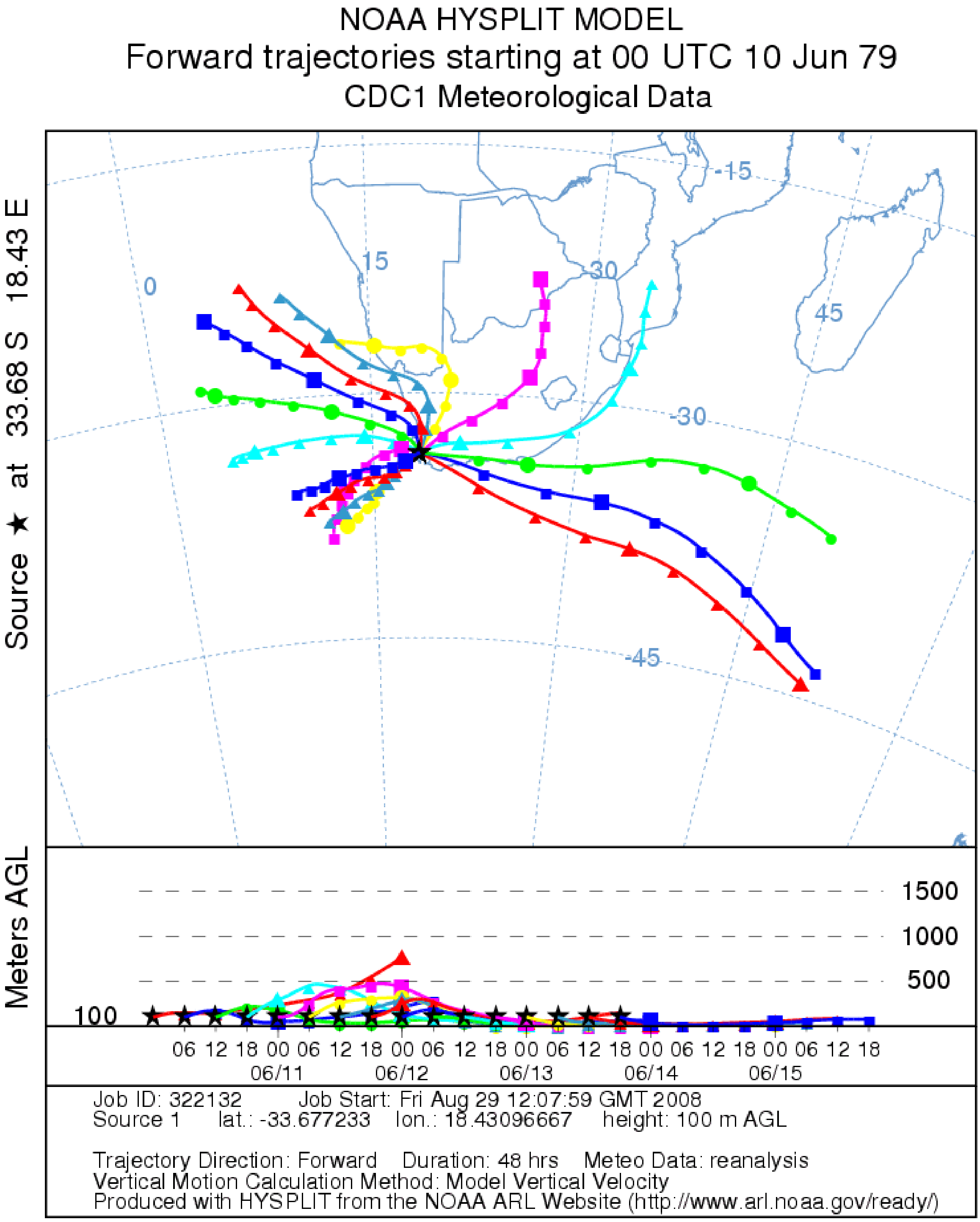


Figure 3-27: Predicted trajectories emitted from Duynefontein site during a left hook situation, as described in Figure 3-26. Each path represents the trajectory at a subsequent hourly interval, with the first 16 hours being represented here. The starting point of each trajectory is indicated in the lower graph with a star.

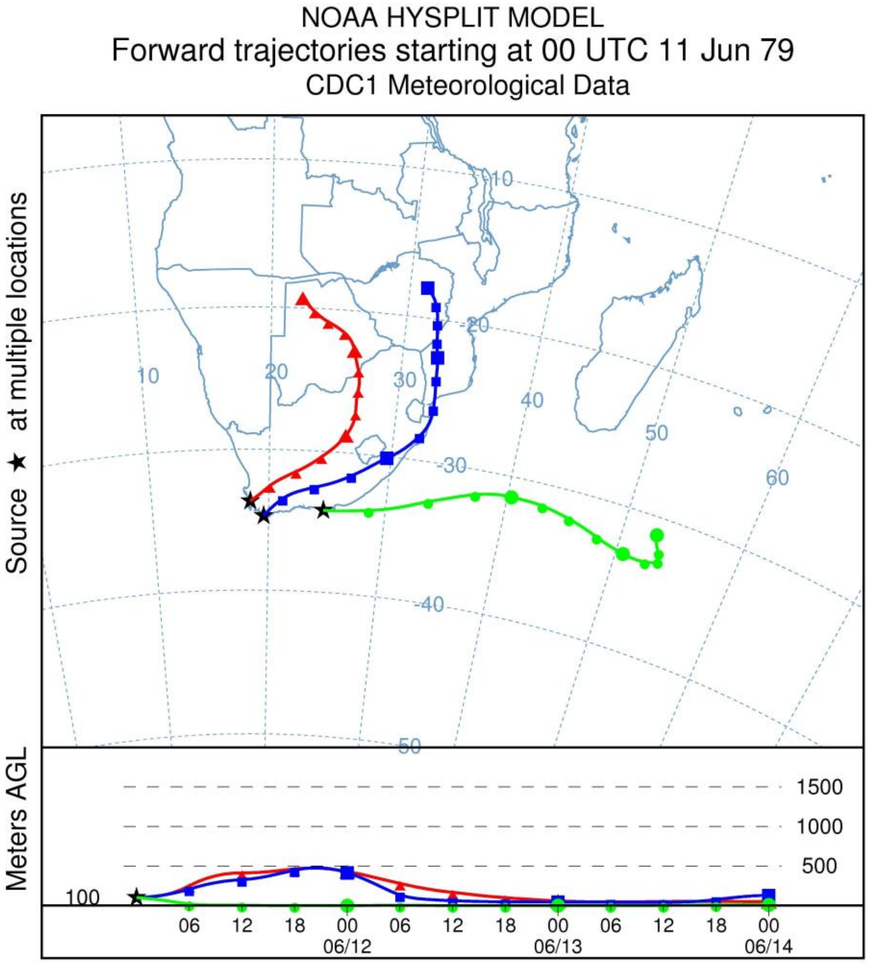


Figure 3-28: Predicted trajectories from three sites during a left hook system developing over the Cape, as described in Figure 3-26 (11 June 1979)

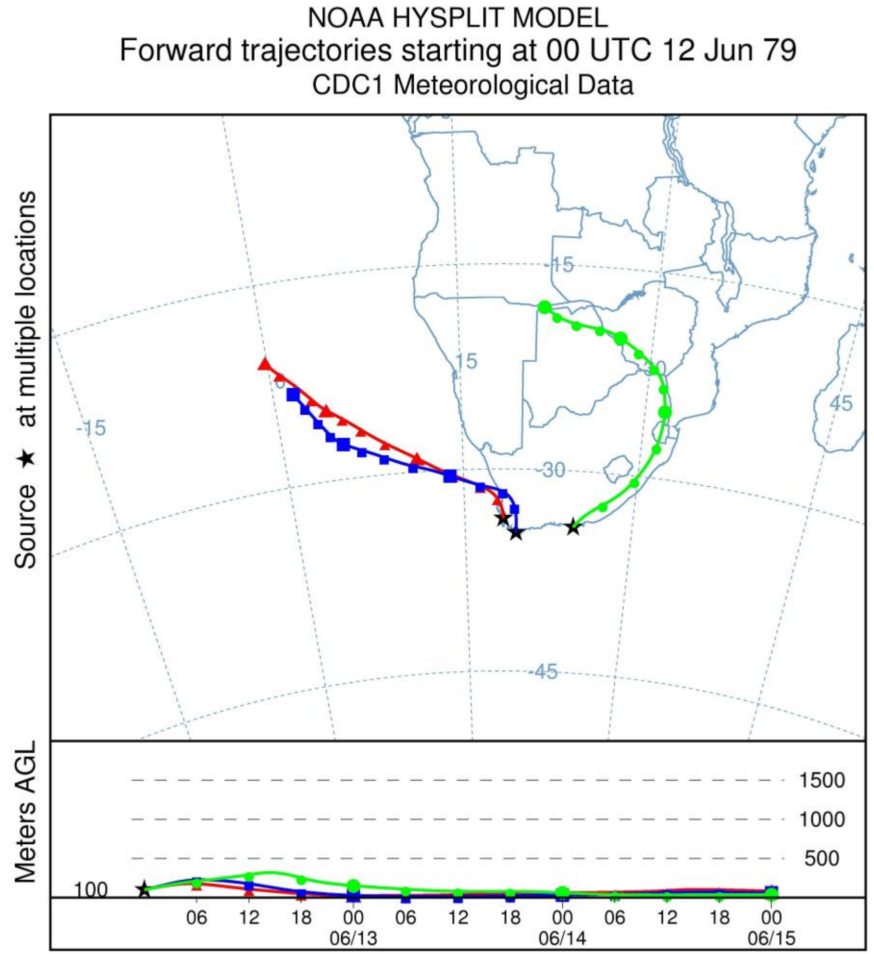


Figure 3-29: Predicted trajectories from three sites with the left hook reaching the Thyspunt site (12 May 1979)

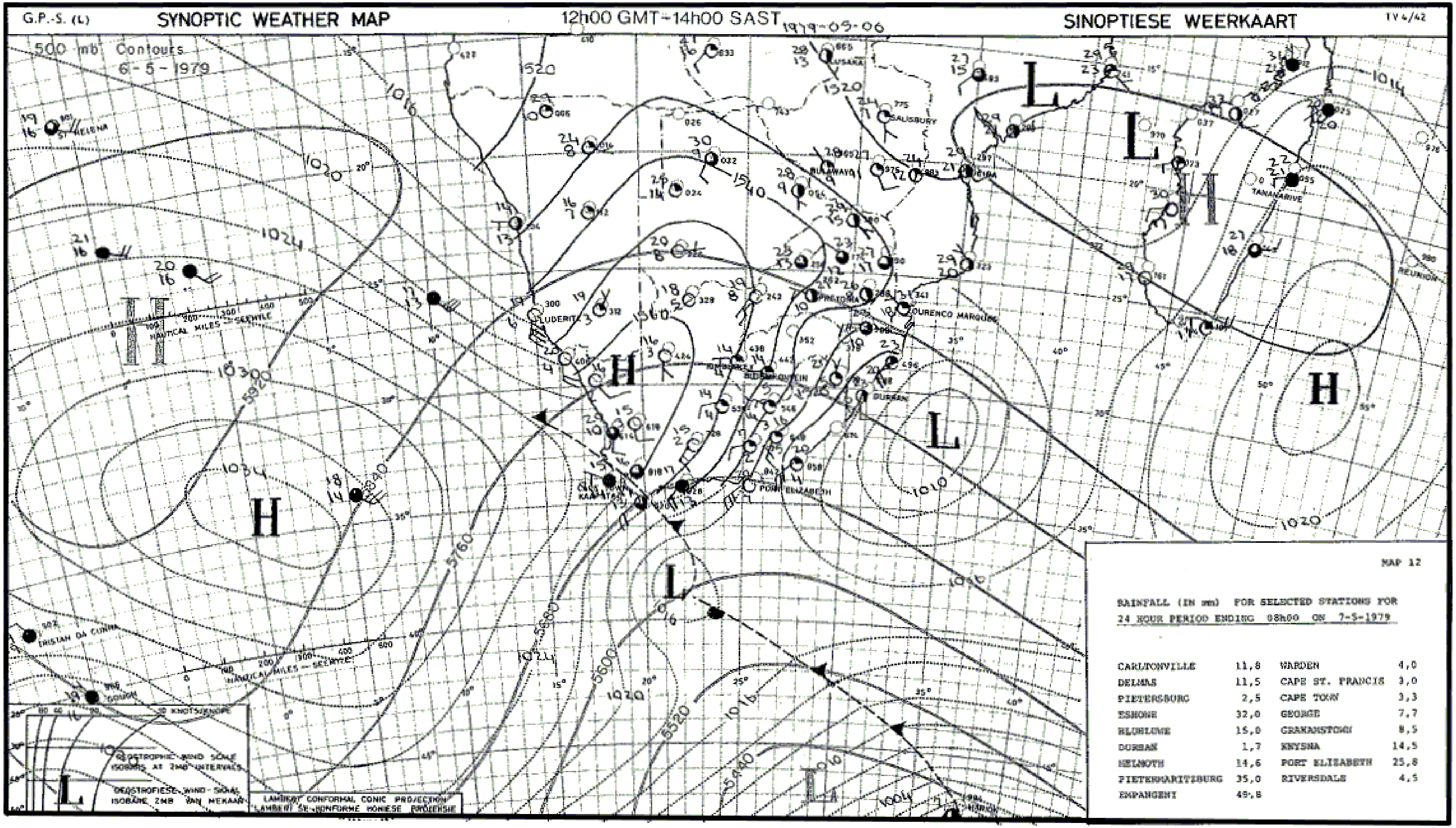


Figure 3-30: Cold front over the Western Cape (6 May 1979)

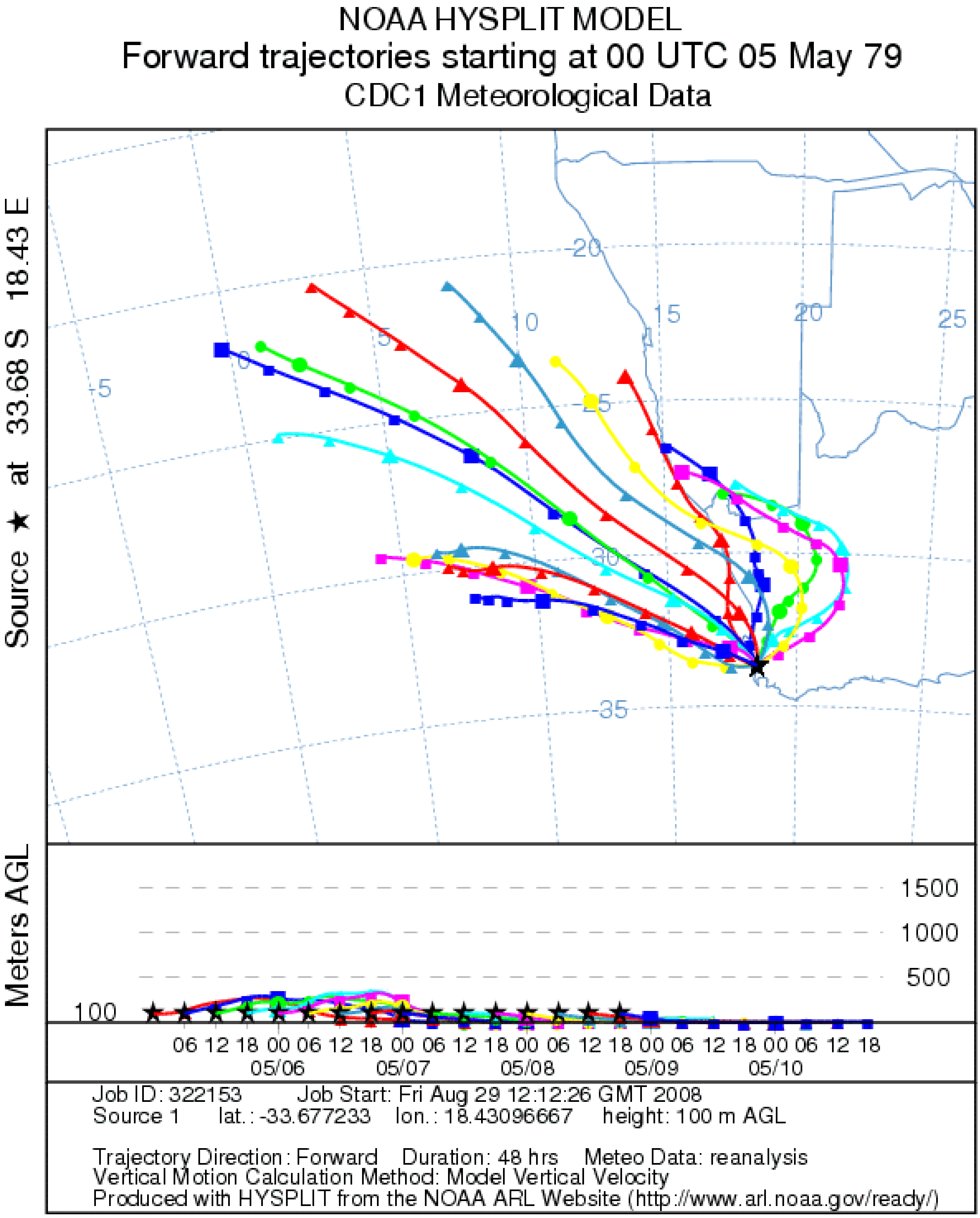


Figure 3-31: Predicted trajectories emitted from Duynefontein site during a cold front over the Western Cape. Each path represents the trajectory at a subsequent hourly interval, with the first 16 hours being represented here. The starting point of each trajectory is indicated in the lower graph with a star.

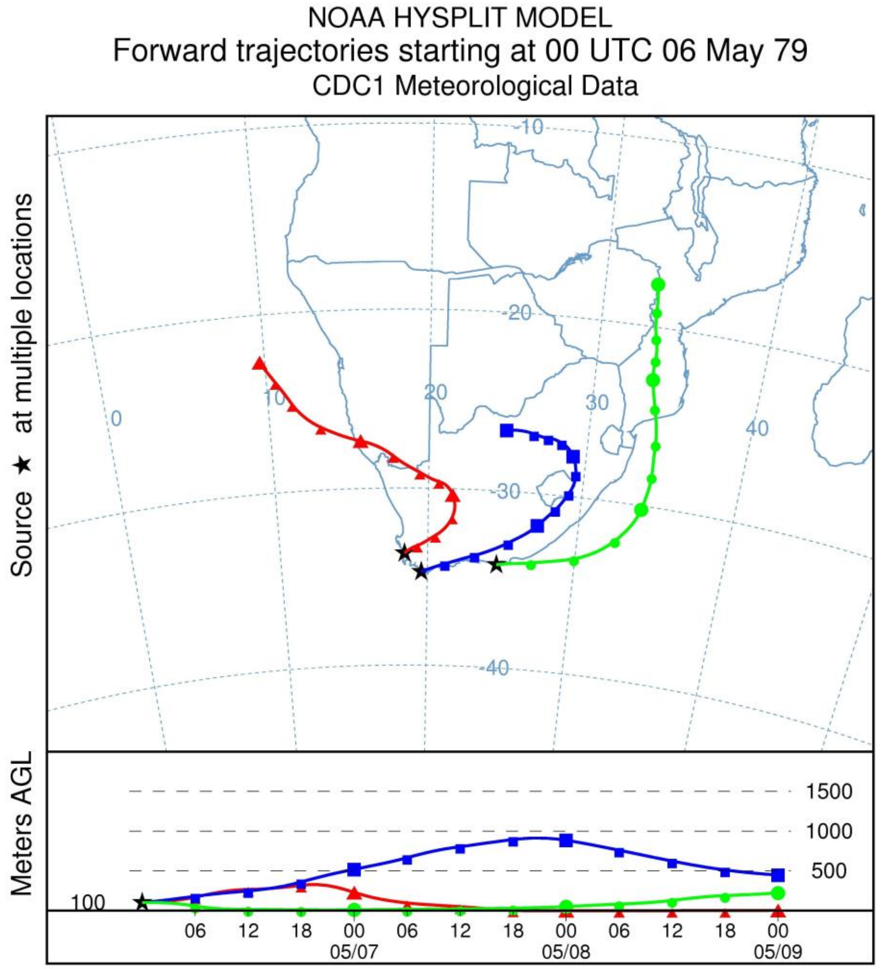


Figure 3-32: Predicted trajectories from three sites during a cold front over the Western Cape, as described in Figure 3-30 (6 May 1979)

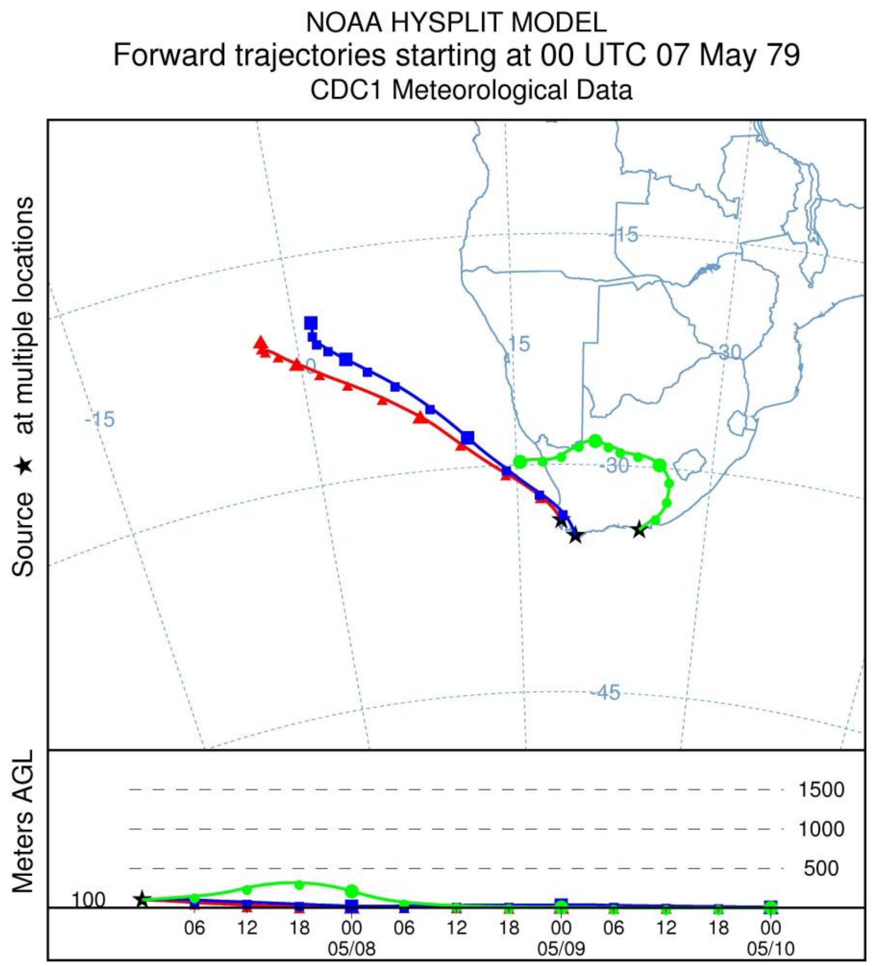


Figure 3-33: Predicted trajectories from three sites during a cold front with a more developed cold front over the rest of South Africa (7 May 1979)

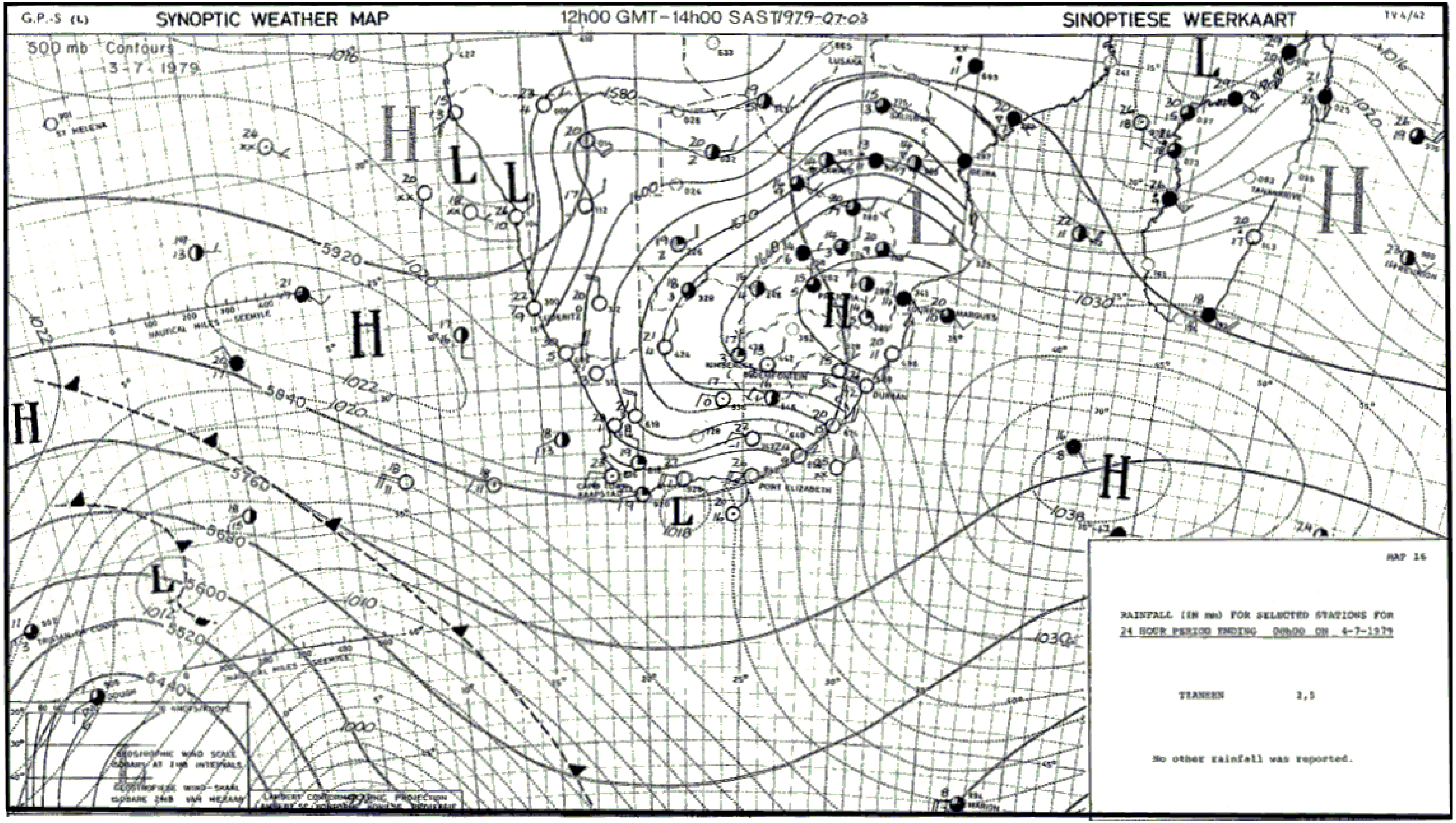


Figure 3-34: Berg Winds Over the Southern Coast Line (3 July 1979)

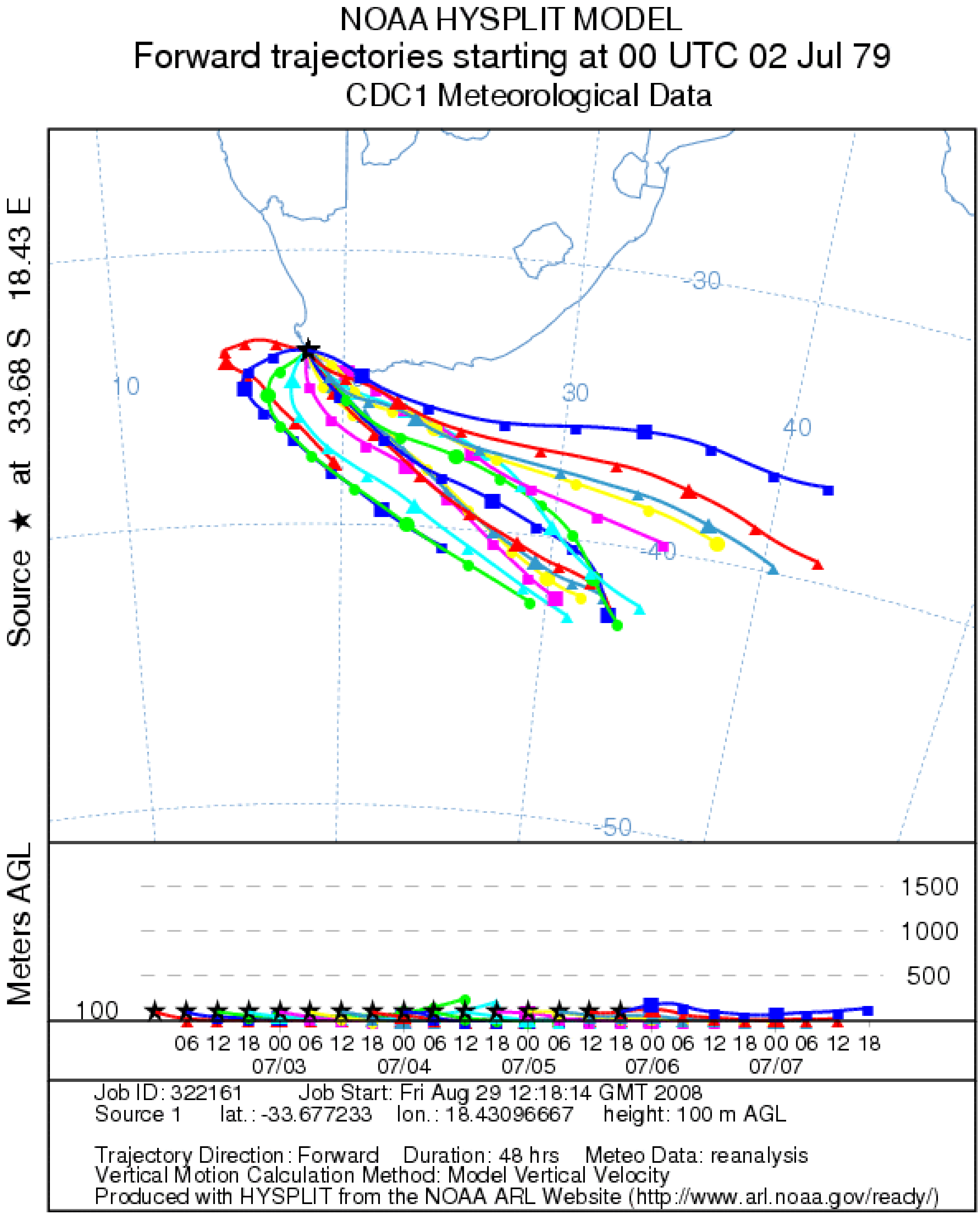
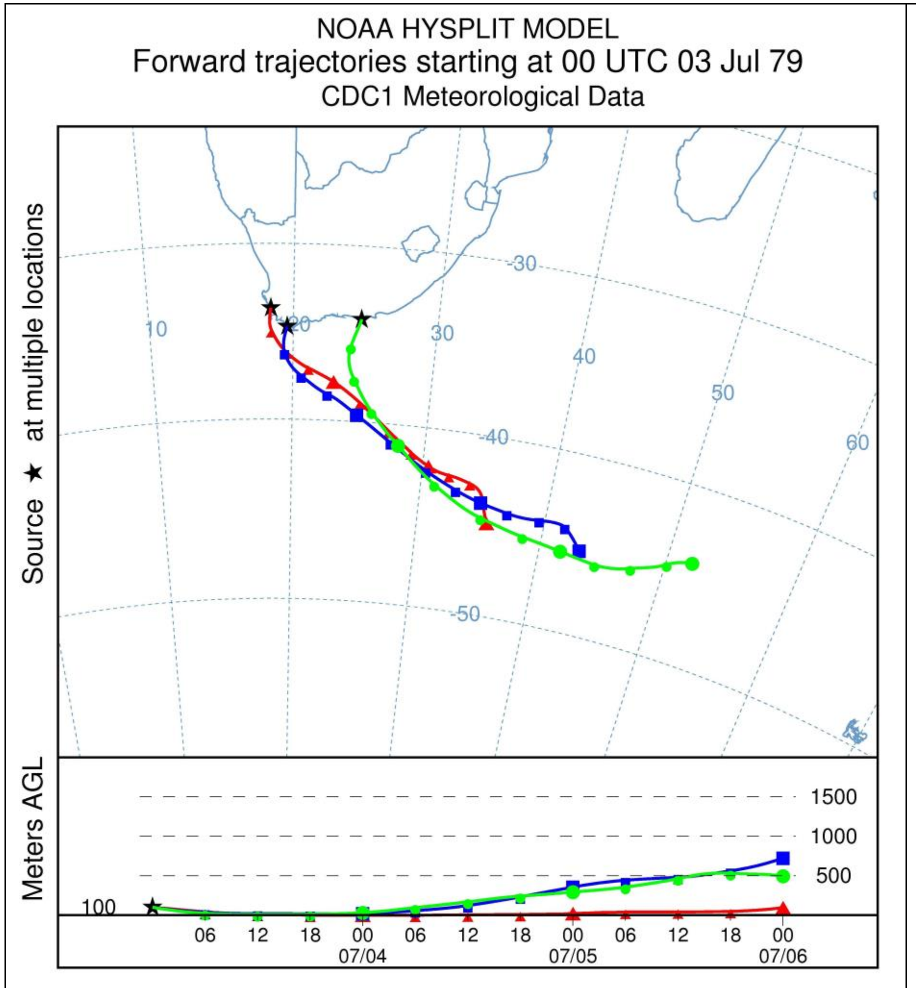


Figure 3-35: Predicted trajectories emitted from Duynefontein during berg wind conditions (2, 3 and 4 July 1979) . Each path represents the trajectory at a subsequent hourly interval, with the first 16 hours being represented here. The starting point of each trajectory is indicated in the lower graph with a star.

The counter-clockwise rotation of the surface high over the east of the country will result in south-eastward flow over the ocean. Since berg winds are also associated with subsidence, vertical mixing is suppressed, meaning that trajectory transport is normally close to the Earth's surface.



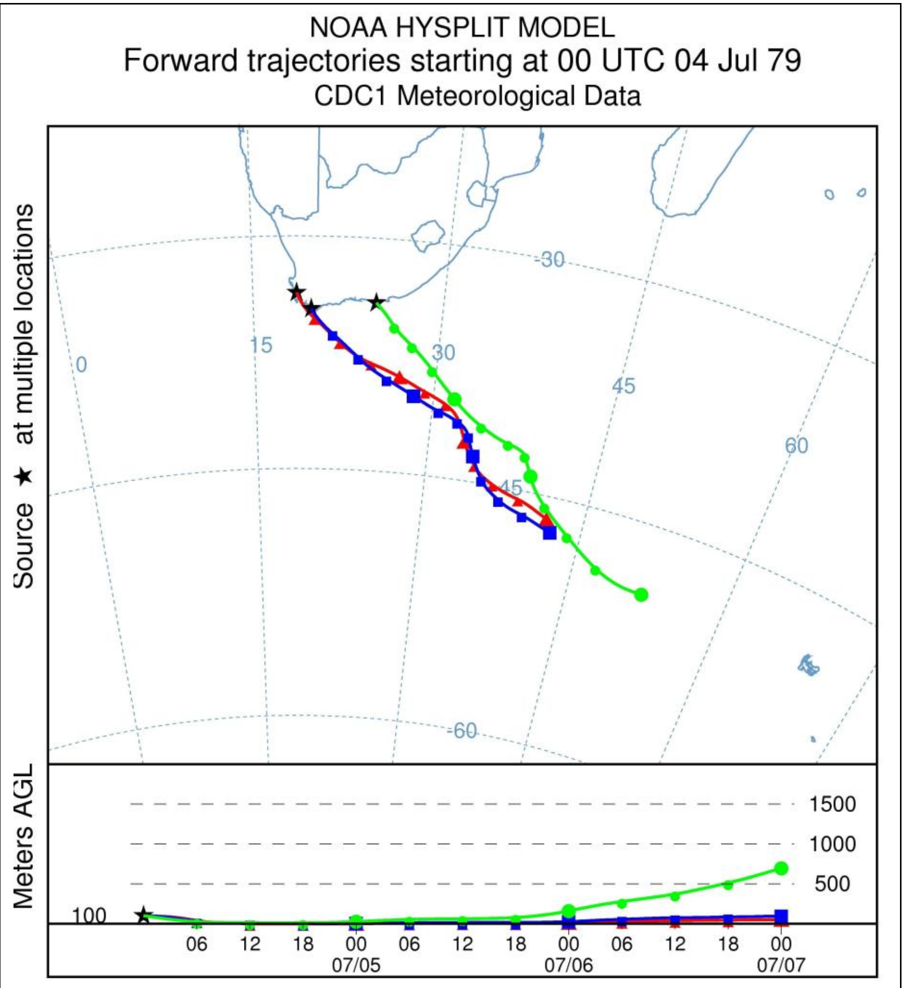


Figure 3-36: Predicted trajectories from three sites during a berg wind condition, as described in Figure 3-38 (3 July 1979)	Figure 3-37: Predicted trajectories from three sites during berg wind conditions on 4 July 1979

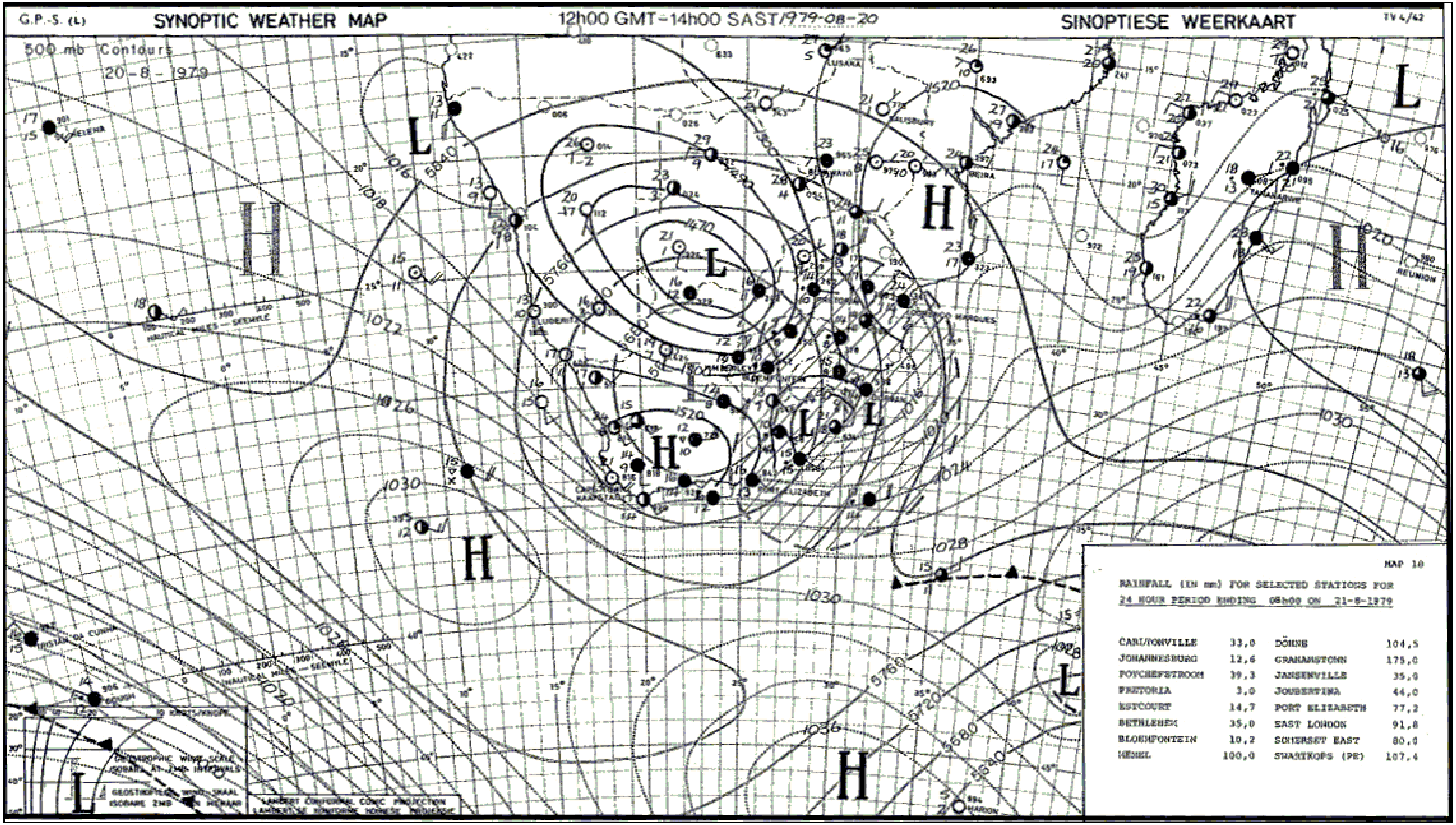


Figure 3-38: "Black Southeaster" conditions (20 August 1979)

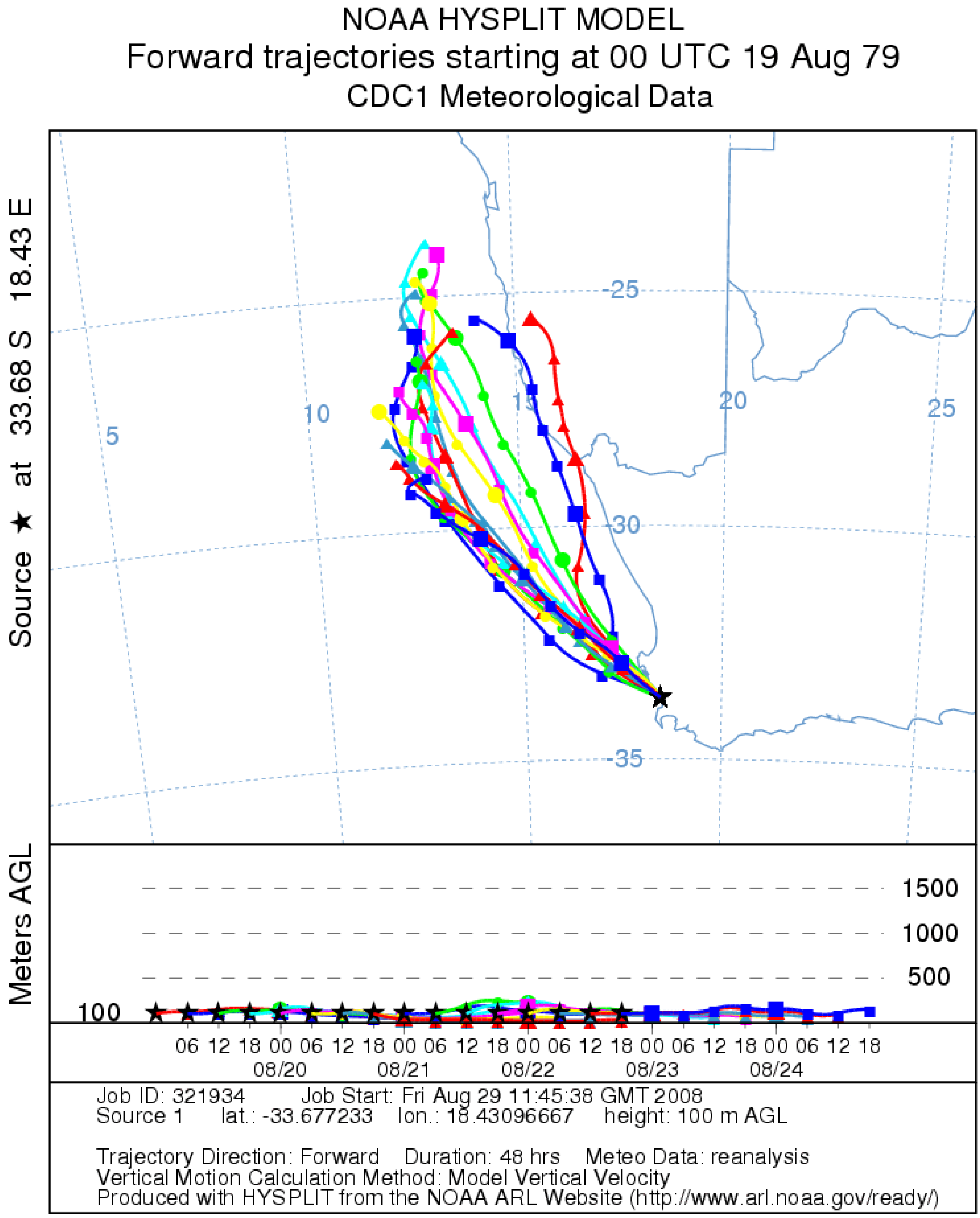
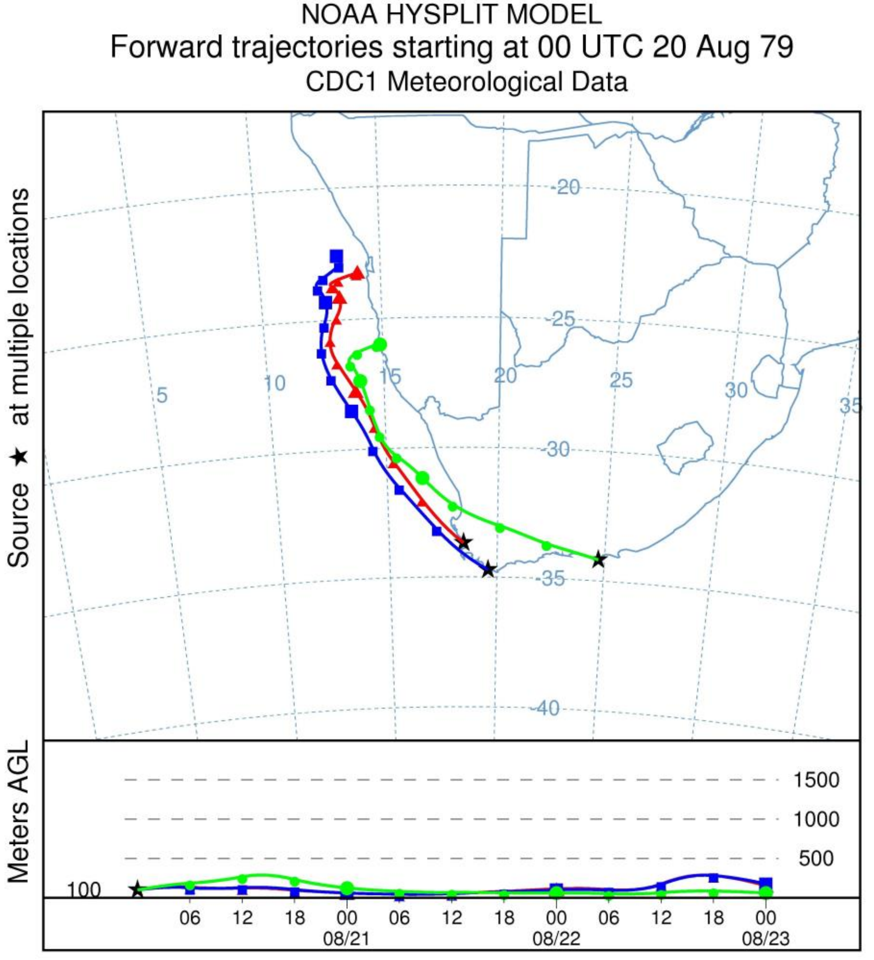


Figure 3-39: Predicted trajectories emitted from Duynefontein site during "black southeaster" wind conditions (19, 20 and 21 August 1979). Each path represents the trajectory at a subsequent hourly interval, with the first 16 hours being represented here. The starting point of each trajectory is indicated in the lower graph with a star.



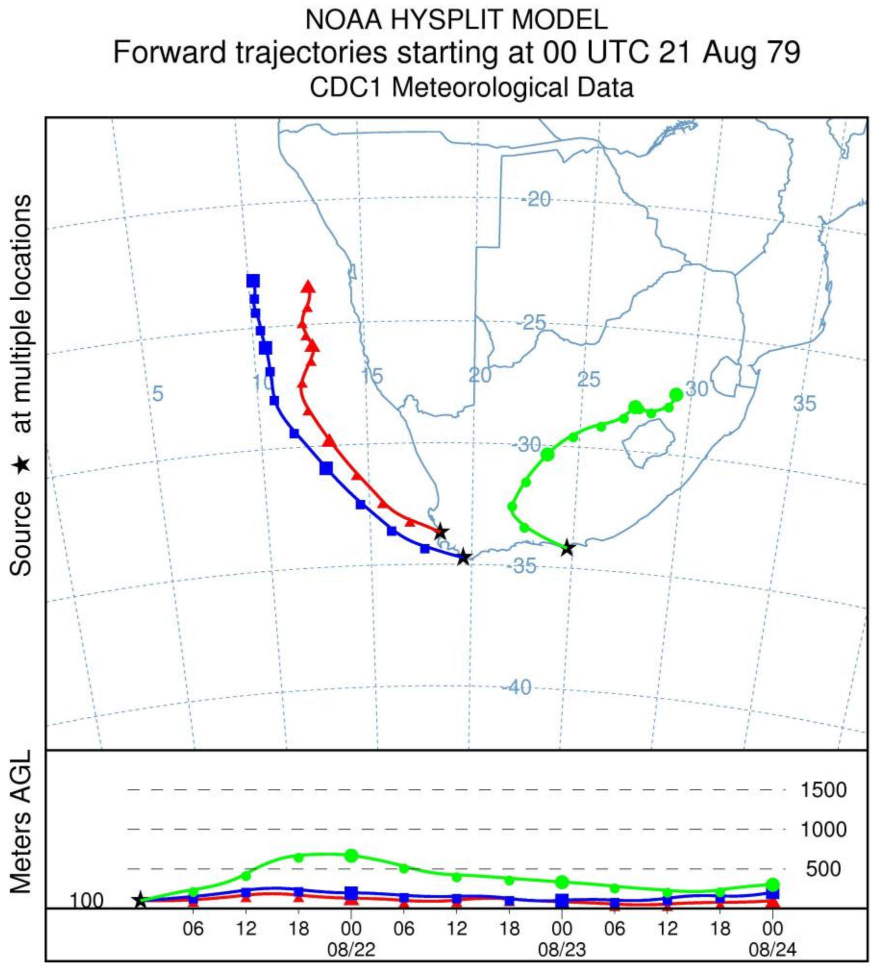


Figure 3-40: Predicted trajectories from three sites during a "black southeaster" wind conditions as described in Figure 3-38 (20 August 1979)

Figure 3-41: Predicted trajectories from three sites during the second day of a "black southeaster" (21 August 1979)

(v) EVENT 5: Black Southeaster over the Western Cape.

The black southeaster develops as a result of a cut-off low in the upper atmosphere, which coincides with an influx of low level moisture from the east (Figure 3 38). A cut-off low is often associated with floods over South Africa, and is a deep low that is “cut off” by the establishment of high pressure ridges to the south of the country. (Extensions of the Atlantic and Indian cyclones that form a westerly wave to the south of the country).

This westerly wave and clockwise rotation around the continental cyclones result in strong winds from the southeast over the Western Cape – from there the name “Black southeaster”. As described by its name, the Black southeaster is associated with strong winds from the southeast, and particle flow will therefore have consistent trajectories towards the northwest, as shown in Figure 3-39. These trajectories are approximately parallel to the South African western and Namibian coastlines.

The clockwise rotation is also witnessed when considering releases from the Bantamsklip and Thyspunt sites, as shown in Figure 3-40 and Figure 3-41. These figures are illustrations of the conditions on 20 and 21 August 1979, respectively

3.4 Air Impacts during the Decommission Phase

The National Nuclear Regulator (NNR) has legislated the need for the establishment of a decommissioning plan for nuclear power stations. The decommissioning plan must be submitted before the nuclear authorisation is granted and at such other frequency thereafter as required by the National Nuclear Regulator. The decommissioning plan must address all the activities necessary commencing from the cessation of the operation to the point where the nuclear authorisation may be surrendered and the period of responsibility terminated. Eskom provided the decommissioning plan developed for Koeberg as the basis for the decommissioning phase of the proposed new nuclear power station. Eskom developed their strategy for decommissioning based on the United States Nuclear Regulatory Commission (US NRC) "Decon" alternative, which states:

"*…the alternative in which the equipment, structures, and portions of a facility and site containing radioactive contaminants are removed or decontaminated to a level that permits the property to be released for unrestricted use shortly after cessation of operations*".

The decommissioning plan was based on the availability of a national repository for all levels of nuclear waste. If a national repository for high level waste is not available 10 years before decommissioning, then Eskom will have to re-assess the 'Decon' decommissioning alternative. It was also assumed that the storage of spent fuel in the nuclear power station will be for a minimum period of ten years.

The stages of decommissioning in the plan are as follows:

- *Phase 1: Preparations.* This phase would be initiated seven years prior to shutdown of the nuclear power station. It includes a detailed list of preparatory functions (e.g. development of a decommissioning project team organisation), investigations & studies (e.g. environmental impact assessment, cost effective feasibility study, compilation of quantities of radioactive material to be secured, control mechanisms, and waste characterisation, including a quantitative estimate of the type, amount, and location of important radionuclides at the end of operating life, etc.), procedures & technical specifications (e.g. final shutdown and de-fuelling sequencing, procedures for occupational exposure control, control and release of liquid and gaseous effluent, processing of radioactive waste, site security, emergency programmes, and industrial safety), and temporary construction facilities to support dismantling activities (e.g. centralised processing areas to facilitate equipment removal and component preparation for off-site disposal, upgrading of roads to facilitate hauling and transportation, fabricate shielding in support of removal and transportation activities, construction of contamination control envelopes, and the procurement of specialised tooling.)
- *Phase 2: Plant shutdown and de-fuelling*. Decisions are made about the final shutdown dates of the units (*viz.* after the winter peaks or at the optimum fuel utilisation stage) and the detailed final plant shutdown and de-fuelling plan is implemented.

- *Phase 3: Implement the spent fuel pool cooling separation plan*. Following the fuel transfer to the spent fuel pool, the spent fuel pool separation plan is implemented.
- *Phase 4: Decommissioning operations*, including the following tasks
    a. Demolition of conventional island and auxiliaries.
    b. Safe enclosure preparation.
    c. Electromechanical dismantling.
- *Phase 5: Spent fuel removal and electromechanical dismantling of the fuel building and auxiliaries*. After 10 years of decay in the spent fuel pool, the last full load of fuel has sufficiently cooled down to be removed from the pools. The spent fuel is then relocated to dual-purpose casks (storage and transport) for transfer to the national repository. Once the spent fuel pools have been emptied, the plant can be decontaminated and decommissioned in accordance with the plan.
- *Phase 6: Demolition of remaining structures and site rehabilitation*.

Given these phases of decommissioning, the phases during which air contaminants can potentially occur include Phase 4, 5 and 6. Whereas both non-radioactive pollutants and radionuclides can occur during Phases 4 and 5, only non-radioactive pollutants (mainly fugitive dust) are expected during Phase 6.

3.4.1 Radionuclides

The detailed action plans for Phase 4 will be reviewed after shutdown to confirm dose rates which had been predicted prior to shutdown. Decontamination of components and piping systems will be conducted, as required to control (minimise) worker exposure. Segmenting the reactor vessel will be performed from a shielded work platform using a contamination control envelope. Water would be maintained in the vessel below the cutting area to minimise the local radiation field. Segments are transferred in-air to containers that are stored under water, for example, in an isolated area of the refuelling canal. Piping would be packaged in industrial containers. The reactor coolant pumps would be sealed with steel plate so as to serve as their own containers. Material which is certified to be free of contamination would be released for unrestricted disposition, e.g. as scrap, or to a local landfill. Contaminated material would be characterised and segregated for additional on-site decontamination, conditioning (disassembly, chemical cleaning, volume reduction and waste treatment), and/or packaging for controlled disposal. A final radiation survey would be conducted to ensure that all radioactive materials in excess of permissible residual levels have been remedied.

The exposure to radiation would be kept to a minimum and below the required dose stipulated by the NNR, through continued measurement. Since these dose limits are based on safe exposure levels, it is expected that the radiation exposure during commissioning would be low.

At the end of the last phase (Phase 6), the sub-surface radionuclide concentrations would again be verified to meet site release requirements.

3.4.2 Non-Radionuclides

The station diesel generator would be kept in operation during Phase 4 to provide emergency power to the spent fuel cooling and clean-up systems during the required heat decay phase for the last core off-loads. Combustion gases, as discussed in Section 3.3.1 will produce an impact on the surrounding area.

Based on the predicted air pollution in Section 3.3.1, none of the combustion products is expected to pose a significant risk during the decommissioning phase.

During Phase 6, the dismantling of the non-essential structures at the site will commence once fuel transfer operations are complete. Since it is not anticipated that these structures would be repaired and preserved after the radiological contamination is removed, prompt dismantling of site structures would clearly be the most appropriate and cost-effective option. The remaining buildings would be removed using conventional demolition techniques for above ground structures, including the nuclear auxiliary, fuel, turbine hall and other site structures. Foundations and exterior walls shall be removed to a nominal depth of one metre below grade whenever possible. The anticipated activities include blasting, coring, drilling, crushing and surface removal. Concrete rubble would be crushed and processed for use as clean fill. Excess rubble would be trucked off-site for disposal as construction debris.

The activities during this phase would generate airborne dust and unless proper management and emission control is applied could potentially generate fugitive dust impacts.

Without detail, only estimates of the impact during demolition can be made. Assuming an active area of about 50% of the nuclear power station footprint, it is estimated that the current daily average SA standard (Air Quality Act) for PM10 of 180 $\mu g/m^3$ can potentially be exceeded up to a distance of about 400 m, and the stricter SANS limit value (SANS 1929:2004) of 75 $\mu g/m^3$ can potentially be exceeded up to a distance of about 1 km. As for construction, these predictions illustrate the worst case scenario, which assumes that no or inadequate fugitive dust control measures are applied.

4 MITIGATION MEASURES

In this section mitigation measures have been identified and recommendations provided. Each affected impact has been re-assessed in terms of significance of the residual impacts.

4.1 Mitigation Objectives

This section includes the mitigation objectives, which would result in a measurable reduction of the impact.

4.1.1 Construction Phase

The mitigation objectives are to ensure compliance of the air quality and fallout rate limits provided in Section 3.1.1. The project particulate air quality guidelines are therefore summarised in Table 4-1.

Table 4-1: Project airborne particulate matter air quality standards

Inhalable Particulate Matter (PM10):			
Maximum 24-hour Average	Limit	75 $\mu g/m^3$	allowed 4 exceedances per year
	Target	50 $\mu g/m^3$	
Annual Average Concentration	Limit	40 $\mu g/m^3$	
	Target	30 $\mu g/m^3$	
Dust deposition:			
Highest Daily	Limit	600 $mg/m^2/day$	allowed 3 exceedances per year
	Target	250 $mg/m^2/day$	
Annual		300 $mg/m^2/day$	

The calculation of airborne particulate emissions and air concentration levels in Section 3.2 clearly showed that the impact due to vehicle entrainment represents the most significant source of particulates. The calculations in Section 3.2 excluded any mitigation. Significant reduction can be achieved through surface treatment of haul roads, with the maximum reduction achievable with tarring of road surfaces. Other surface treatment alternatives include chemical stabilisation and the application of regular water spray.

To illustrate the effect of tarred roads on the air pollution impact, the predicted PM10 air concentrations and fallout rates were calculated and summarised in Figure 4-1 to Figure 4-6.

It is clear that the impact of particulates, using the guidelines given in Table 4-1, would mostly be confined to the proposed nuclear power station corridor and entirely within the Eskom property boundaries.

Figure 4-1: Predicted maximum daily average inhalable particle (PM10) concentration levels during construction at Duynefontein (Mitigated)

Figure 4-2: Predicted maximum daily average particle fallout rates (mg/m²/day) during construction at Duynefontein (Mitigated)

Figure 4-3: Predicted maximum daily PM10 concentration levels (μg/m³) during construction at Bantamsklip (Mitigated)

Figure 4-4: Predicted maximum daily average particle fallout rates (mg/m²/day) during construction at Bantamsklip (Mitigated)

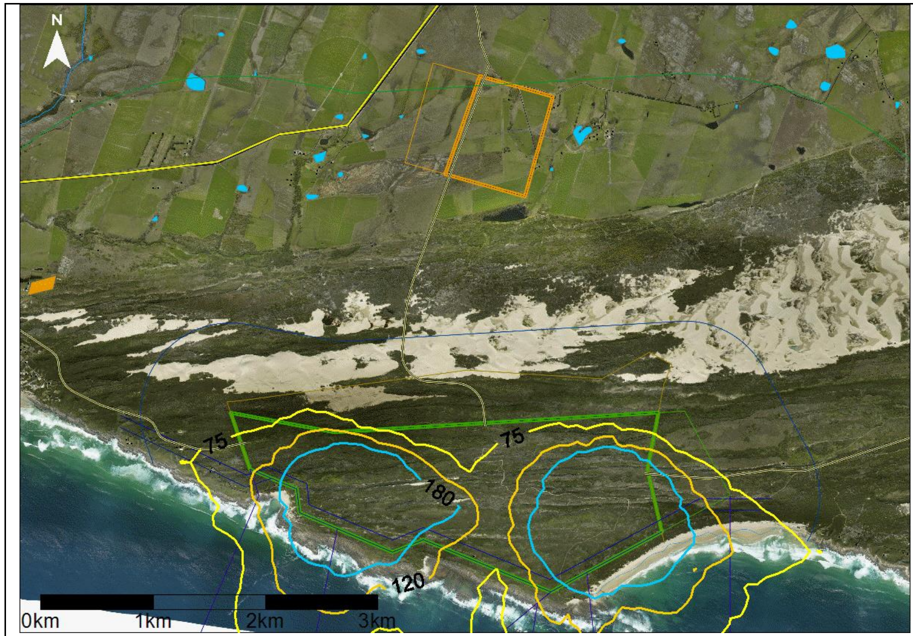


Figure 4-5: Predicted maximum daily average PM10 concentration levels (µg/m³) during construction at Thyspunt with Road Option A and the envelope of the nuclear power station on the east or west of the corridor (Mitigated)

Figure 4-6: Predicted maximum daily average particle fallout rates (mg/m²/day) during construction at Thyspunt with Road Option A and the envelope of the nuclear power station on the east or west of the corridor (Mitigated)

4.1.2 Operational Phase

4.1.3 Non-Radioactive Sources

The project particulate air quality guidelines are therefore summarised in Table 4-2. These are based on the air quality limits provided in Section 3.1.1.

Table 4-2: Project air quality standards

Pollutant	Averaging Period	Limit Value ($\mu g/m^3$)	Limit Value (ppb)	Frequency of Exceedance
Carbon Monoxide	1 hour	30000	26000	88
	8 hour	10000	8700	11
Nitrogen Dioxide	1 hour	200	106	88
	1 year	40	21	0
PM10	24 hour	75	-	4
	1 year	40	-	0
Sulphur Dioxide	10 minutes	500	191	526
	1 hour	350	134	88
	24 hour	125	48	4
	1 year	50	19	0

4.1.4 Radionuclide Emissions

As discussed in Appendix A, the Government Notice No. R 388 of 2006 stipulates an annual effective dose limit for members of the public from all authorised actions of 1 mSv. The Regulation additionally provides a dose constraint, which is applicable to an average member of the critical group within the exposed population. This effective dose should not exceed 0.25 mSv (or 250 µSv) in a year from potential exposure from the site.

4.1.5 Decommissioning Phase

A decommissioning plan for the proposed nuclear power station will need to be developed for the site ensuring compliance with the dose limits stipulated by the NNR.

4.2 Recommended mitigation measures

4.2.1 Construction Phase

The most significant impact during the construction phase would be as a result of airborne particulates from fugitive dust sources, including wheel entrainment, wind erosion of exposed surfaces, and construction activities.
(a) Recommended Controls

It is essential to have effective dust and emission controls for every potentially dust generating activity to protect the health and safety of the workforce on site as well as reduce statutory nuisance and health risk to local residents and people in the vicinity. An emission minimisation plan is regarded essential in the situation where construction activities are conducted very close to residential and other sensitive receptors. Although the proposed project is relatively far removed from the residential areas a management plan is still recommended. The most significant source (between 80% and 90%) of fugitive dust emissions was shown to be wheel entrainment on unpaved roads. It is, therefore, recommended to have the initial focus on the reduction of emissions from road surfaces. This can be achieved through regular watering of unpaved surfaces, applying chemical dust suppressants, or most preferably, tarring of road surfaces.

In areas were tarring is not a practical option the management plan should have, as a minimum, watering schedules of unpaved roads and other activities that could be mitigated with water sprays.

The following additional mitigation measures during the construction phase are recommended:

- Vegetation is to only be removed when soil stripping is required. These areas should be limited to include only those areas required for development, hereby reducing the surface area exposed to wind erosion. Adequate demarcation of these areas should be undertaken.
- Control options pertaining to topsoil removal, loading and dumping are generally limited to wet suppression. The options exist in scheduling this activity to coincide with periods when soil moisture can be expected to be optimal. However, if topsoil handling occurs when soil is too wet, the soil structure may be compromised. Decisions pertaining to the timing of topsoil stripping require the balancing of various aspects.
- Where it is logistically possible, control methods for unpaved roads should be utilised to reduce the re-suspension of TSP. Recommended measures are discussed in Table 4-3.
- Air quality monitoring at the nearest neighbours should be initiated.
- The length of time where open areas are exposed should be restricted. Construction of infrastructure should not be delayed after land has been cleared and topsoil removed.
- Dust suppression methods should be where logistically possible, implemented at all areas that may / are exposed for long periods of time.
- Any drilling and blasting should be delayed under unfavourable wind and atmospheric conditions (e.g. wind directions towards nearby Duynefontein

village and Melkbosstrand [Duynefontein site] or Pearly Beach [Bantamsklip site] or Oyster Bay [Thyspunt]).

- Where logistically feasible, seasonal meteorological conditions should be taken into consideration during construction activities (i.e. precipitation and wind field).

Table 4-3: Control measures for unpaved roads

Control	Technique	Description
Source extent reduction	Speed reduction Traffic reduction	These controls limit the amount of traffic on an unpaved road or strict enforcement of speed limits.
Source improvement	Paving Gravel surface	These controls alter the road surface. These techniques are “once-off” control methods, therefore ensuring that periodic treatments are not normally required.
Surface Treatment	Watering Chemical stabilization	These control techniques require periodic reapplications. These treatments fall into two main categories, (i) wet suppression and (ii) chemical stabilization. Water is usually applied, utilising a truck with a gravity or pressure feed. This is only a temporary measure and periodic reapplications are necessary to achieve a substantial level of control efficiency Chemical suppressants have less frequent reapplication requirements. These are designed to alter the roadway, such as cementing loose material into a fairly impervious surface (hereby simulating a paved surface) or forming a surface which attracts and retains moisture (simulating wet suppression)

Table 4-4 contains a summary list of control measures for all significant dust generating sources. The table is not intended to contain a complete list of controls and should therefore not be seen as the only means of controls and mitigation measures. The main objective of the controls and mitigation measures remains to satisfy the project standards given in Table 4-1 as acceptance criteria.

Dust and gaseous generating activities should be detailed to an extent that a risk matrix can be developed. This process would allow Eskom to categorise the level of risk of its particular planned work and prioritise each activity. This categorisation could be in the form of the matrix, where for example, the probability of releasing dust or particles is given a value between 1 and 5 (corresponding to “improbable”, “unlikely”, “likely”, “very likely”, “almost certain”) and similarly, severity is given a value ranging from 1 to 5 corresponding to “negligible”, “slight”, “moderate”, “high” and “very high”. An activity with a negligible severity of impact and low probability of releasing dust is categorised as low risk.

Table 4-4: Mitigation measures to reduce the impact of air pollution during construction activities

Activity	Control Measure
Vehicle Movements	In dry or windy conditions, dust can become airborne through the movement of vehicles. Findings from large construction sites have shown that unpaved haul routes account for the most significant proportion of fugitive dust emissions. If paving is not option regular water spraying has to be applied.
	Clear labelling of all vehicles associated with the contract will help to identify any vehicles that are causing unnecessary re-suspended or fugitive dust emissions.
	Minimising dust and mud from the site entrance or exit will help prevent fugitive emissions being spread outside the site boundary by site vehicles. The control measures outlined below should provide the most effective ways to prevent re-suspension of road dust from a construction site so that no mud or dirt is deposited outside the boundary: • Provide a control zone at the site entrance to protect residents (this could include wheel washing facilities) • Put in place procedures for effective cleaning of vehicles and inspection. Since these vehicles could carry mud onto the road surface leading to the construction site, as a minimum wheel washing would be necessary. If this proves not to be adequate, total vehicle washing must be applied. • Provide washing facilities at the exits including hose pipes, adequate water supply and pressure and mechanical wheel spinners or brushes • Ensure that loading of materials is done with the lowest drop height and those vehicles carrying dusty materials are securely and properly covered before they leave the site. • Enter all information in a log book including all vehicles entering and leaving the site • Sweeping tarred road entrances to reduce mud and dust carry through
Excavation and earthworks	Excavation and earthworks can be a potential source of dust if they are not properly controlled, especially in dry and windy weather. If possible, such activities should be avoided on exceptionally dry or windy days.
	The following controls must be considered to stabilise surfaces and minimise disturbance as much as possible: • Re-vegetate dry, exposed areas to stabilise surfaces • Only remove secure covers in small areas during work and not all at once • All activities must be damped down, especially during dry weather
Stockpiles	Maintaining stockpiles on site should be avoided where possible.
	If stockpiles are necessary, any piles of dusty materials should be securely covered to reduce dust generation and the following measures should be in place: • Do not build steep sided stockpiles or mounds or those that have sharp changes in shape • Keep stockpiles or mounds away from the site boundary and sensitive receptors. Take into account the predominant wind direction to reduce the likelihood of affecting sensitive receptors.

Activity	Control Measure
	• Make sure that stockpiles are maintained for the shortest possible time • Seed, re-vegetate or turf long term stockpiles to stabilise surfaces or use surface binding agents • Where possible, enclose stockpiles or keep them securely sheeted • Erect fences of similar height and size to the stockpile to act as wind barriers and keep these clean using wet methods. Porous fences or hedges often make the most suitable shelter. • Store fine or powdery material (under 3 mm in size) inside buildings or enclosures • Minimise drop heights to control the fall of materials
Crushing Plants	Although it was not given whether a crushing plant would be located on site, they have the potential to make a significant contribution to dust emissions on top of those from general site activities. The following processes all have the potential to generate dust. Recommended controls are provided.
	Loading and unloading of materials: • Containment • Suppression • Reduce drop heights (through variable height conveyors or chutes)
	Silos: • Dust arrestment (bag or cartridge filters)
	Aggregate stockpiles: • Wind design management through fencing, bunding etc • Suppression (water and/or suppressants, well positioned spray guns and sufficient coverage by sprays) • Covering • Conveyors and transfer • Containment (wind boards) • Reduce drop heights • Appropriate siting away from receptors • Blending and packing • Containment • Designated areas • Reduce drop height • Dust arrestment (bag or cartridge filters)
Waste Disposal	All waste material should be re-used or safely removed from site according to appropriate legislation

Activity	Control Measure
	Bonfires are not recommended on site and if necessary, they should be supervised at all times
Vehicle Tailpipe Emissions	Ensuring that vehicles are in good working condition
	Minimizing idling of equipment when not in use.

This could include one that is far removed from sensitive receptors and very limited dust generation, e.g. casting concrete on the western side of the property. A high risk would be an activity that has the capability of generating significant amounts of dust and it is towards the residential area on the eastern side. This may be scraping activity on a windy day. Mitigation measures therefore need to take into account seasonal variations, and specifically the occurrence of rainy and windy months. Mitigation measures put in place will help to reduce the impact of a high risk site to medium or low. A general checklist of activities associated with construction is contained in Appendix D.

As part of the management plan, a method statement should be completed. The contents should be built on the issues identified in the risk matrix, and should include the following:

- Inventory of all dust generating activities and emission control methods to be used (see checklists in the Appendix D);
- Identification of an authorised on-site person responsible person for air pollution – most likely the appointment responsible for health and safety;
- Details and procedure on using a site log book (to record information including exceptional incidents causing dust episodes and action taken, identification and details of vehicle washing, site inspections); and
- Details of any fuel stored on site.

(b) Recommended Monitoring and Evaluation Programme

A comprehensive monitoring regime which includes measurement of levels in worker areas and areas of the community sensitivity is recommended. The monitoring regime needs to include the following:

- Parameters to be monitored;
- Monitoring locations;
- Monitoring interval;
- Data and data analysis requirements for monitoring reports; and
- Reporting interval.

Monitoring measures outlined in the South African National Standards, SANS 1929:2004 are recommended. The tools for effective dust monitoring include:

- Baseline sampling;
- Control site sampling;
- Dust deposition gauges (provides long term data);
- High volume samplers (quantitative data over 24 hr periods);
- Continuous particle monitors (provides data relevant to short-term events);
- Size-selective samplers (samples dust in size fractions); and
- Personal exposure samplers (worn by workers).

A discussion on appropriate suspended particulate samplers is given in Appendix E. The most suitable sampler type depends on the specific objectives of monitoring. Pertinent monitoring objectives in the case of the proposed nuclear power station are expected to include: on-going compliance evaluation, on-going estimation of contribution to airborne particulate concentrations to background levels, and evaluation of the effectiveness of dust control measures implemented during the construction period.

Given the above objectives, and noting that international reference methods are likely to be the preferred approach during the promulgation of South African regulations for air quality monitoring, it is recommended that Eskom invest in the purchase of a filter-based, on-line monitor (e.g. TEOM, BAM). Real-time, continuous transfer of the measured concentrations (via telemetry or satellite) would contribute significantly to the use of such measurements to trigger rapid responses to pollution episodes. However, considering that the period of dust generation would be limited to the construction phase, Eskom could perhaps invest in a number of the less costly, non-filter based automatic monitors (e.g. DustTrak, DustScan, Topas). These instruments provide an indication of the range of particulate concentrations and despite possibly not being the preferred method for compliance monitoring, would provide the construction environmental manager with a means of tracking progress made through emission reduction measure implementation.

The monitors should be located in areas that would allow the quantification of potentially increased levels of airborne particulate matter in sensitive areas. Therefore, samplers/monitors should be placed at the residential boundary closest to the construction site. Directional sampling would ensure that observations from the construction activity are captured.

Air pollution control should be based on the project air quality limits given in Section 5.1.

4.2.2 Operational Phase

(a) Non-Radionuclide Emissions

No additional emission controls are required.

(b) Radionuclide Emissions

No additional emission controls are required.

4.2.3 Decommissioning Phase

The impact during the decommissioning phase was qualitatively assessed based on the assumption that the decommissioning plan would be the same as that developed for Koeberg. A site-specific decommissioning plan must be developed according to the most recent requirements stipulated by the NNR.

5 ENVIRONMENTAL ASSESSMENT

Prior to assessing the impact of the proposed emissions from the proposed nuclear power station, reference needs to be made to the environmental regulations and guidelines governing the emissions and impact of such operations. 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. The ambient air quality limits are intended to indicate safe daily exposure levels for the majority of the population, including the very young and the elderly, throughout an individual's lifetime. Such limits are given for one or more specific averaging periods, typically 10 minutes, 1-hour average, 24-hour average, 1-month average, and/or annual average. A discussion of these is given in Appendix A, and a summary of the relevant criteria given in Section 3.1. These criteria were used as guidance to determine the intensity of the impact.

5.1 Air Impact Criteria

5.1.1 Impact Rating Methodology

In accordance with Government Notice R.385 of 2006, promulgated in terms of Section 24 of the NEMA and the criteria drawn from the IEM Guidelines Series, Guideline 5: Assessment of Alternatives and Impacts, published by the DEA (April 1998) it is required to describe and assess the potential impacts in terms of the following criteria:

(a) Nature of the impact

This is an evaluation of the type of effect the construction, operation and management of the proposed nuclear power station development would have on the affected environment. This may be positive, negative or neutral.

(b) Extent of the impact

This is a provision of the spatial impact of the operation, i.e. local (limited to the site and its immediate surroundings); or whether the impact will be at a regional or national scale.

(c) Duration of the impact

The project duration and its residual impact determines whether it would be short-term (0-3 years), medium-term (4-8 years), long-term (>9 years) or permanent impact.

(d) Intensity

This provides for the inclusion of the magnitude of the impact. The air concentration and dose criteria supplied in Section 3.1 will be used to determine the intensity of the impacts during the construction and operational phases.

The system for assessing intensity of the impact is summarised in Table 5-1. It is based on the SANS 1929 recommended criteria for managing of ambient air quality:

Table 5-1: Criteria for defining intensity of impact

Intensity	Criteria	Comment
LOW	Levels below 50 % guidelines/limits	Where the impact affects the environment in such a way that natural, cultural and social functions and processes are minimally affected
MEDIUM	Levels above 50 % guidelines/limits but with number of exceedances within the allowable frequency	Where the affected environment is altered but natural, cultural and social functions and processes continue albeit in a modified way; and valued, important, sensitive or vulnerable systems or communities are negatively affected
HIGH	Levels above guidelines/limits with number of exceedances more than the allowable frequency	Where natural, cultural or social functions and processes are altered to the extent that the natural process will temporarily or permanently cease; and valued, important, sensitive or vulnerable systems or communities are substantially affected.

(e) Consequence

The consequence of the potential impacts have been determined according to the main criteria for determining the consequence of impacts, namely the extent, duration and intensity of the impacts, as defined according to Table 5-2.

Table 5-2: Convention for assigning consequence ratings

Consequence Rating	Combination of extent, duration, intensity and the potential for impact on irreplaceable resources
LOW	A combination of any of the following • Intensity, duration, extent and impact on irreplaceable resources are all rated low • Intensity is low and up to two of the other criteria are rated medium • Intensity is medium and all three other criteria are rated low
MEDIUM	• Intensity is medium and at least two of the other criteria are rated medium
HIGH	• Intensity and impact on irreplaceable resources are rated high, with any combination of extent and duration • Intensity is rated high, with all of the other criteria being rated medium or higher.

(f) Probability of occurrence

The probability of the impact is described as improbable (low likelihood), probable (distinct possibility or 50% chance), highly probable (50 to 90% chance) or definite (impact will occur regardless of any prevention measures) as summarised in Table 5-3.

Table 5-3: Convention for assigning consequence ratings

LOW	It is highly unlikely or less than 50 % likely that an impact will occur.
MEDIUM	It is between 50 and 74 % certain that the impact will occur.
HIGH	It is more than 75 % certain that the impact will occur or it is definite that the impact will occur.

(g) Significance Rating

The overall significance of the impacts was defined based on the result of a combination of the consequence rating and the probability rating, as defined above. The rating categories are defined in Table 5-4.

The significance therefore defines the level to which the impact will influence the proposed development and/or environment in any way. It determines whether mitigation measures need to be identified and implemented or whether the resource is irreplaceable and/or the activity has an irreversible impact.

Table 5-4: Convention for assigning significance ratings

Significance Rating	Consequence x Probability
LOW Significance	• Low consequence and Medium Probability • Low consequence and Low Probability
LOW - MEDIUM Significance	• Low consequence and High Probability • Medium consequence and Low probability
MEDIUM Significance	• Medium consequence and Medium probability • Medium consequence and High probability • High consequence and Low probability
MEDIUM - HIGH Significance	• High consequence and Medium Probability
HIGH Significance	• High consequence and High Probability

(h) Degree of confidence in predictions

The degree of confidence (low, medium or high) was based on the available information and assessment tools.

(i) Cumulative

Where necessary, the predicted incremental impacts of the proposal were included in the current air pollution impacts, i.e. cumulative impacts would be:

- LOW when there is still significant capacity of the environmental resources within the geographic area to respond to change and withstand further stress;
- MEDIUM if the capacity of the environmental resources within the geographic area to respond to change and withstand further stress is reduced; or
- HIGH when the capacity of the environmental resources within the geographic area to respond to change and withstand further stress has been or is close to being exceeded.

(j) Reversibility

This defines the ability of the impacted environment to return to its pre-impacted state once the cause of the impact has been removed. This may be

- HIGH when the impacted natural, cultural or social functions and processes will return to their pre-impacted state within the short-term;
- MEDIUM when the impacted natural, cultural or social functions and processes will return to their pre-impacted state within the medium term; or
- LOW when the impacted natural, cultural or social functions and processes will never return to their pre-impacted state.

(k) Irreplaceability

This defines the ability of an environment aspect to be replaced should it be impacted on.

(l) Mitigation measures

The development of mitigation measures in order to reduce <u>and prevent</u> the significance of the impact.

5.2 Impact Rating Results

The impact rankings for the three sites are given in Table 5-5 (Duynefontein), Table 5-6 (Bantamsklip) and

Table 5-7 (Thyspunt), respectively.

5.2.1 Construction Phase

The predicted impact during the construction phase is assumed to apply to any of the nuclear plant designs.

5.2.2 Operational Phase

The non-radioactive emissions essentially only consist of intermittent emissions and include ammonia, formaldehyde, carbon monoxide, sulfur dioxide, oxides of nitrogen and airborne particulate matter.

5.2.3 Decommissioning Phase

This phase was qualitatively assessed, using the proforma decommissioning plan developed for Koeberg.

Table 5-5: Significance rating for air pollution impacts at Duynefontein (See Section 5.1.1: Impact Identification for full descriptions)

Impact	Nature	Intensity	Extent	Duration	Impact on irreplaceable resources	Consequence	Probability	SIGNIFICANCE
1. Construction - Gaseous emissions	*Negative*	*Low*	*Medium*	*Medium*	*Low*	*Low*	*Medium*	*Low*
Mitigated (a)	*Negative*	*Low*	*Medium*	*Medium*	*Low*	*Low*	*Medium*	*Low*
2. Construction - PM10 emissions	*Negative*	*High*	*Medium*	*Medium*	*Low*	*Medium*	*High*	*Medium*
Mitigated (b)	*Negative*	*Low*	*Medium*	*Medium*	*Low*	*Low*	*Medium*	*Low*
3. Construction - Fallout	*Negative*	*Low*	*Medium*	*Medium*	*Low*	*Low*	*High*	*Low - Medium*
Mitigated (b)	*Negative*	*Low*	*Medium*	*Medium*	*Low*	*Low*	*Medium*	*Low*
4. Operational - Non-radionuclide emissions	*Negative*	*Low*	*Medium*	*High*	*Low*	*Medium*	*Medium*	*Medium*
Mitigated (c)	*Negative*	*Low*	*Medium*	*High*	*Low*	*Medium*	*Medium*	*Medium*
5. Operartional - Radionuclide emissions	*Negative*	*Low*	*Medium*	*High*	*Low*	*Medium*	*High*	*Medium*
Mitigated (c)	*Negative*	*Low*	*Medium*	*High*	*Low*	*Medium*	*High*	*Medium*
6. Cumulative impacts	*Negative*	*Low*	*Medium*	*High*	*Low*	*Medium*	*High*	*Medium*
Mitigated	*Negative*	*Low*	*Medium*	*High*	*Low*	*Medium*	*High*	*Medium*

Notes:
(a) - See mitigation measures recommended in Section 4.2 (Table 4-4)
(b) - See mitigation measures recommended in Section 4.2 (Table 4-3 and Table 4-4)
(c) - No additional emission controls are required

Table 5-6: Significance rating for air pollution impacts at Bantamsklip(See Section 5.1.1: Impact Identification for full descriptions)

Impact	Nature	Intensity	Extent	Duration	Impact on irreplaceable resources	Consequence	Probability	SIGNIFICANCE
1. Construction - Gaseous emissions	*Negative*	*Low*	*Medium*	*Medium*	*Low*	*Low*	*Medium*	*Low*
Mitigated (a)	*Negative*	*Low*	*Medium*	*Medium*	*Low*	*Low*	*Medium*	*Low*
2. Construction - PM10 emissions (b)	*Negative*	*High*	*Medium*	*Medium*	*Low*	*Medium*	*High*	*Medium*
Mitigated	*Negative*	*Low*	*Medium*	*Medium*	*Low*	*Low*	*Medium*	*Low*
3. Construction - Fallout	*Negative*	*Low*	*Medium*	*Medium*	*Low*	*Medium*	*High*	*Medium*
Mitigated (b)	*Negative*	*Low*	*Medium*	*Medium*	*Low*	*Low*	*Medium*	*Low*
4. Operational - Non-radionuclide emissions	*Negative*	*Low*	*Medium*	*High*	*Low*	*Medium*	*Medium*	*Medium*
Mitigated (c)	*Negative*	*Low*	*Medium*	*High*	*Low*	*Medium*	*Medium*	*Medium*
5. Operartional - Radionuclide emissions	*Negative*	*Low*	*Medium*	*High*	*Low*	*Medium*	*High*	*Medium*
Mitigated (c)	*Negative*	*Low*	*Medium*	*High*	*Low*	*Medium*	*High*	*Medium*
6. Cumulative impacts	*Negative*	*Low*	*Medium*	*High*	*Low*	*Medium*	*High*	*Medium*
Mitigated	*Negative*	*Low*	*Medium*	*High*	*Low*	*Medium*	*High*	*Medium*

Notes:
(a) - See mitigation measures recommended in Section 4.2 (Table 4-4)
(b) - See mitigation measures recommended in Section 4.2 (Table 4-3 and Table 4-4)
(c) - No additional emission controls are required

Table 5-7: Significance rating for air pollution impacts at Thyspunt (See Section 5.1.1: Impact Identification for full descriptions)

Impact	Nature	Intensity	Extent	Duration	Impact on irreplaceable resources	Consequence	Probability	SIGNIFICANCE
1. Construction - Gaseous emissions	*Negative*	*Low*	*Medium*	*Medium*	*Low*	*Low*	*Medium*	*Low*
Mitigated (a)	*Negative*	*Low*	*Medium*	*Medium*	*Low*	*Low*	*Medium*	*Low*
2. Construction - PM10 emissions	*Negative*	*High*	*Medium*	*Medium*	*Low*	*Medium*	*High*	*Medium*
Mitigated (b)	*Negative*	*Low*	*Medium*	*Medium*	*Low*	*Low*	*Medium*	*Low*
3. Construction - Fallout	*Negative*	*High*	*Medium*	*Medium*	*Low*	*Medium*	*High*	*Medium*
Mitigated (b)	*Negative*	*Low*	*Medium*	*Medium*	*Low*	*Low*	*Medium*	*Low*
4. Operational - Non-radionuclide emissions	*Negative*	*Low*	*Medium*	*High*	*Low*	*Medium*	*Medium*	*Medium*
Mitigated (c)	*Negative*	*Low*	*Medium*	*High*	*Low*	*Medium*	*Medium*	*Medium*
5. Operartional - Radionuclide emissions (c)	*Negative*	*Low*	*Medium*	*High*	*Low*	*Medium*	*High*	*Medium*
Mitigated	*Negative*	*Low*	*Medium*	*High*	*Low*	*Medium*	*High*	*Medium*
6. Cumulative impacts	*Negative*	*Low*	*Medium*	*High*	*Low*	*Medium*	*High*	*Medium*
Mitigated	*Negative*	*Low*	*Medium*	*High*	*Low*	*Medium*	*High*	*Medium*

Notes:
(a) - See mitigation measures recommended in Section 4.2 (Table 4-4)
(b) - See mitigation measures recommended in Section 4.2 (Table 4-3 and Table 4-4)
(c) - No additional emission controls are required

5.3 "No-Go" Option

The "No-Go" option refers to the impact associated with the site without the proposed construction and operation of the nuclear power station. With this scenario, it is not possible to define any alternative development proposals.

5.3.1 Duynefontein

Without the proposed nuclear power station, the impact at the Duynefontein site would be as described in the baseline assessment (Section 2.4.1). The "no-go" option would therefore be the same as the current air quality impact, which is considered to be of LOW *significance* for non-radioactive compounds and LOW *significance* for radionuclide emissions.

5.3.2 Bantamsklip

The current air quality at the Bantamsklip site is regarded very clean with regards to non-radioactive criteria pollutants, such as oxides of nitrogen, sulphur dioxide and carbon monoxide. Airborne particulate concentrations may become elevated during windy conditions due to wind erosion of dune sand. Any development on the site that would increase vehicle numbers, introduce combustion sources (ovens, boilers, heaters, etc.) or human population would have the potential of increasing the levels of these criteria pollutants. The significance depends on the alternative options, and could result in a HIGH significance.

Since the current baseline dose at the site is not known, it is not quantitatively possible to provide an accurate "no-go" impact rating for radioactivity. However, limits set by the NNR are sufficiently low to be within natural occurring radiation levels. As an example, the background dose measured in Woodstock for 2008 was 744 µSv/annum (Section 2.4.1), compared to the NNR dose constraint of 250 µSv.

Accidental releases from the proposed nuclear power station change the comparison of impacts to the "no-go" option. According to the NNR, the dose resulting from DBAs must be below 50 mSv per event. This could likely be above the natural occurring radioactivity at the site and as such, unless radioactive material is used in any alternative developments, the radio nuclear impact of the "no-go" option would be rated lower.

5.3.3 Thyspunt

The air quality at the Thyspunt site is similar to Bantamsklip and the same discussion applies to this site.

6 CONCLUSIONS AND RECOMMENDATIONS

The air quality impact of a proposed nuclear power station was assessed for three alternative sites, namely

- Duynefontein (Western Cape) located adjacent to the existing Koeberg Power Station, Cape Town);
- Bantamsklip (Western Cape) located 10 km south-east of Pearly Beach; and
- Thyspunt (Eastern Cape) located west of Port Elizabeth and approximately 15 km west of Cape St. Francis.

In Eskom's selection process, they focused on two types of nuclear power plants for consideration, namely Light Water Reactors (LWR) and Heavy Water Reactors (HWR). LWRs utilise ordinary water ("light water", H_2O) to moderate and cool the reactors. HWR use "heavy water" or deuterium oxide (D_2O) as a neutron moderator and coolant. New Generation Reactors (Generation IV) were not considered as these are still regarded by Eskom to be in developmental stages. The LWR category is further subdivided into the Pressurised Water Reactor (PWR) and Boiling Water Reactor (BWR). Eskom proposes to employ the PWR technology. However the final reactor selection has not been done. The number of reactor units would be determined by Eskom's requirement for 4000 MWe power generation. The impact assessment was completed on the envelope of a number of reactor designs. The predicted radionuclide dose envelopes for the three sites are given in Figure 6-1 (Duynefontein), Figure 6-2 (Bantamsklip) and Figure 6-3 (Thyspunt), respectively.

6.1 Conclusions

Based on the predicted impacts of both non-radioactive and radionuclide air pollution, the assessment concludes that none of the sites need to be discarded for the proposed nuclear power station.

The predicted impacts would be similar at all three sites, and specific mitigation is recommended during the construction phase only.

Due to the predicted low impact of radionuclide emissions under normal operation, no additional mitigation is required for radionuclide emissions.

The main information gaps/limitations can be grouped into meteorological data and the air pollution emission data:

- A comparison of 18 months' on site meteorological data collected at Thyspunt and Bantamsklip with the SAWS data concluded that the predicted dose calculations would be very similar with the two data sets. The conclusions reached in this assessment would therefore not be different when using a longer period of onsite meteorological data.
- Whilst emission rates for the construction phase were based on estimated volumes of excavated material and the activities associated with this phase, differences from this schedule may occur at the time of actual construction. However, in spite of the potential differences in predicted impacts with such

different schedules, it is nonetheless believed that the implementation of the recommendations below would limit the impacts to acceptable levels.

- The impact assessment is very sensitive to the definition of the radionuclide source term. An attempt was made to bind the impact through using the emissions from two reactor technologies. Any significant changes to the source term, outside this envelope would have a direct effect on the predicted dose. It is therefore important that the source term of the final selection be checked against the assumptions made in this assessment. The conclusions reached in this assessment will not be supported if the source term is outside of the envelope used in this assessment.

6.1.1 Construction Phase

The main pollutant of concern during construction would be airborne particulates. The likely sources of these air quality impacts would be fugitive dust emissions from general construction activities (clearance, excavation, scraping, road surfaces etc) and the potential for elevated ambient air quality levels caused by transportation emissions from the vehicles and equipment used by the workforce used in construction. Predicted impacts during the construction phase were shown to have a MEDIUM significance if no or limited mitigation measures are applied. The impact would primarily be due to the generation of airborne particulates on unpaved haul roads. This impact can be reduced to LOW significance with management plans and emission controls in place.

6.1.2 Operational Phase

Potential sources of non-radioactive air emissions during the operational phase include:

- Carbon, sulphur and nitrogen oxides in the exhaust gases from engines of the backup electricity generators;
- Formaldehyde and carbon monoxide emitted by the insulation when installations go back into operation after servicing; and
- Ammonia discharged as the temperature rises in the steam generators during start-up.

The predicted impacts of non-radioactive emissions during the operational phase at Bantamsklip and Thyspunt were shown to have a LOW significance. In spite of other air pollution sources in the region of Duynefontein (specifically nitrogen dioxide), based on a baseline air concentration monitoring campaign, the cumulative impact rating at the Duynefontein site is of LOW significance.

During normal operation, small quantities of radiological materials are released to the environment. This assessment only considered inhalation, cloud immersion and radiation from soil deposition pathways. Ignoring the ingestion pathway, the predicted effective dose from these pathways indicates LOW *significance*. This rating applies for all three sites.

The dispersion simulations included a number of identified Design Basis Accidents (DBA). The predicted highest whole body dose following such accidental releases from the nuclear power station was shown to be below the maximum acceptable limit of 50 mSv for a single event, as stipulated by the NNR. The highest whole body dose at 1 km downwind from the nuclear power station would be 49 mSv.

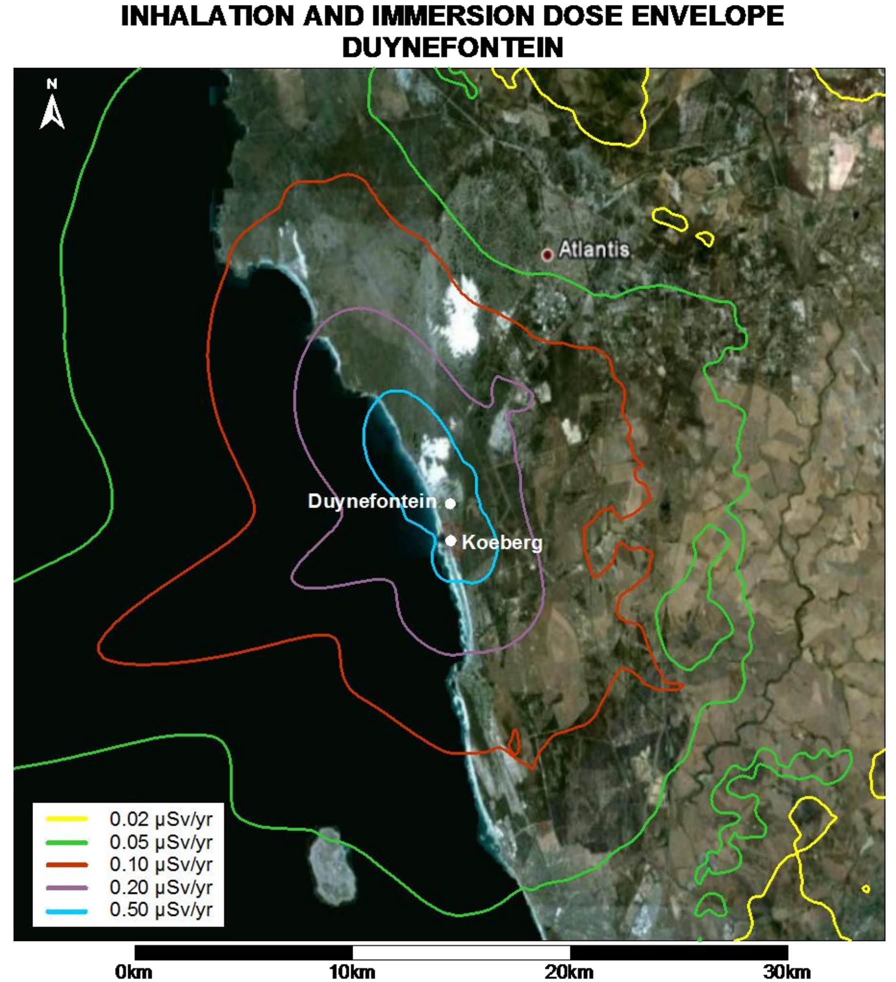


Figure 6-1: Predicted maximum cumulative annual inhalation and external radiation dose (µSv) for Duynefontein using 30 year equilibrium for deposition and 4000 MWe based on the nuclear power station envelope

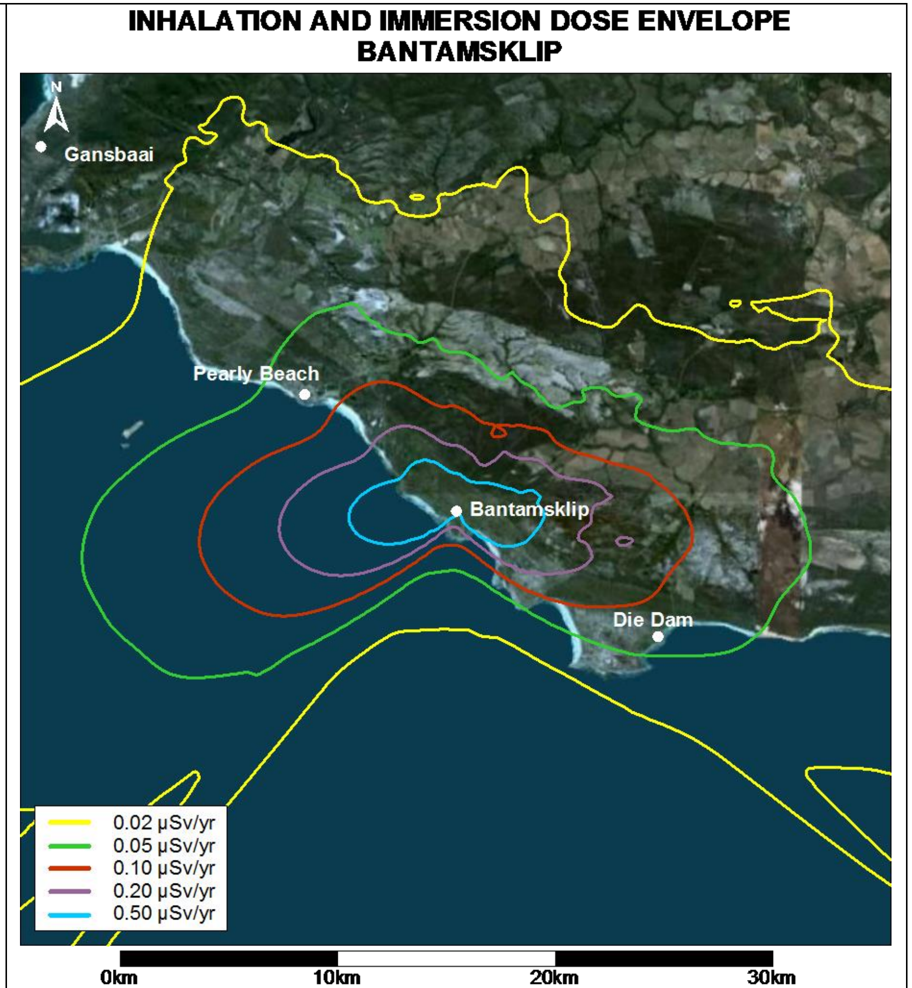


Figure 6-2: Predicted maximum annual inhalation and external radiation dose (µSv) for Bantamsklip using 30 year equilibrium for deposition and 4000 MWe based

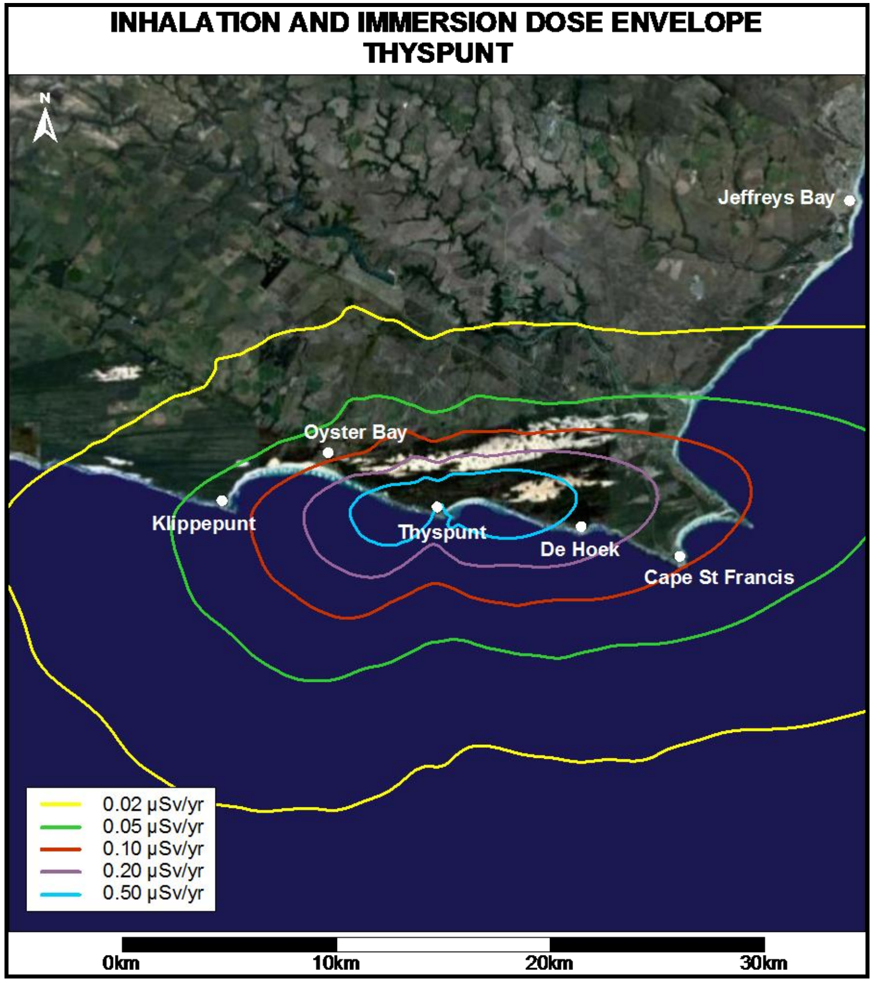


Figure 6-3: Predicted maximum annual inhalation and external radiation dose (µSv) for Thyspunt site using 30 year equilibrium for deposition and 4000 MWe based on the envelope of the AP1000 and EPR designs.

6.1.3 Decommissioning Phase

Eskom provided the decommissioning plan developed for Koeberg as the basis for the decommissioning phase of the proposed new nuclear power station. Eskom developed their strategy for decommissioning based on the United States Nuclear Regulatory Commission (US NRC) “Decon” alternative, which states:

“*…the alternative in which the equipment, structures, and portions of a facility and site containing radioactive contaminants are removed or decontaminated to a level that permits the property to be released for unrestricted use shortly after cessation of operations*”.

The exposure to radiation would therefore be kept to a minimum and below the required dose stipulated by the NNR, through continued measurement. Since these dose limits are based on safe exposure levels, it is expected that the radiation exposure during commissioning would be low.

The plan consists of six phases. At the end of the last phase (Phase 6), the sub-surface radionuclide concentrations would again be verified to meet site release requirements.

The emergency diesel generator at the nuclear power station would be kept in operation during Phase 4 to provide emergency power to the spent fuel cooling and clean-up systems during the required heat decay phase for the last core off-loads. Based on the predicted air pollution none of the combustion products is expected to pose a significant risk during the decommissioning phase.

During Phase 6, the dismantling of the non-essential structures at the site will commence once fuel transfer operations are complete. The activities during this phase would generate airborne dust and unless proper management and emission control is applied could potentially generate fugitive dust impacts.

6.1.4 “No-Go” Option

The “No-Go” option refers to the impact associated with the site without the proposed construction and operation of the nuclear power station. With this scenario, it is not possible to define any alternative development proposals.

Duynefontein Site

Without the proposed nuclear power station at the Duynefontein site, the “no-go” option would be the same as the current air quality impact, which is considered to be of LOW *significance* for non-radioactive compounds and MEDIUM *significance* for radionuclide emissions.

Bantamsklip and Thyspunt Sites

The current air quality at the Bantamsklip and Thyspunt sites is regarded very clean with regards to non-radioactive criteria pollutants, such as oxides of nitrogen, sulphur dioxide and carbon monoxide. Any alternative developments on the site which would increase vehicle numbers, introduce combustion sources (ovens, boilers, heaters, etc.) or human population could have the potential of increasing the levels of these criteria pollutants. The significance depends on the alternative options, and could result in a HIGH significance.

Since the current baseline dose at these two sites are not known, it is not quantitatively possible to provide an accurate "no-go" impact rating for radioactivity. Given the low dose limits set by the NNR, normal emission would result in dose levels within natural occurring radiation levels. However, in the event of an accidental release, it is expected that the dose would be above the natural occurring radioactivity at the site and as such, unless radioactive material is used in any alternative developments, the radio nuclear impact of the "no-go" option would be rated lower.

6.2 Recommendations

- The predicted impacts of unmitigated emissions during the construction phase were shown to have a HIGH significance.
    - A comprehensive list of recommendations has been provided in Section 5.2.1.
    - This impact can be reduced to LOW significance with management plans and emission controls in place.
    - An emission minimisation plan is regarded essential in the situation where construction activities are conducted very close to residential and other sensitive receptors.
    - The most significant source (between 80% and 90%) of fugitive dust emissions was shown to be wheel entrainment on unpaved roads. It is, therefore, recommended to have the initial focus on the reduction of emissions from road surfaces. This can be achieved through regular watering of unpaved surfaces, applying chemical dust suppressants, or most preferably, tarring of road surfaces.
    - In areas were tarring is not a practical option the management plan should have, as a minimum, watering schedules of unpaved roads and other activities that could be mitigated with water sprays.
    - In addition to road surface treatment, it is recommended to utilise the construction mitigation management checklist given in Appendix D, or a suitably modified version thereof.
- The recommended air quality monitoring programme provided in Section 5.2.1 should preferably be initiated a year prior to construction. This would provide an adequate baseline air concentration trend which would incorporate all seasons. This programme must include both non-radionuclide and radionuclide compounds (as stipulated by the NNR);
- No additional mitigation measures are required for routine operational emissions of radionuclides. However, once the final reactor technology has been decided, Eskom need to confirm that the emissions from the selected technology conform to the envelope used in this assessment and that such emissions can be maintained throughout the nuclear power station's lifecycle. This includes a thorough assessment of the reliability and maintenance of the high efficiency particulate air (HEPA) filters which would be used to control radiological air emissions from the nuclear power station;
- Similarly, the successful technology supplier must illustrate how incidental and accidental releases would conform to the NNR's requirements and how these would be kept As Low As Reasonably Achievable (ALARA);
- The impact during the decommissioning phase was qualitatively assessed based on the assumption that the decommissioning plan would be the same as that developed for Koeberg. A site-specific decommissioning plan must be developed according to the most recent requirements stipulated by the NNR.

- It is recommended to ensure that the emissions from the backup power generators perform according to the vendor specifications, which the assessment was based on. Although continuous emissions monitoring (CEM) would be preferred for particulates and oxides of nitrogen, regular stack sampling campaigns would be adequate given the intermittent nature of operation. It is recommended that the first three isokinetic sampling campaigns should also include sulfur dioxide analysis.
- Air dispersion modelling must be repeated using the source terms for normal and upset emissions of the successful vendor and onsite meteorological data prior to construction of the nuclear power station. The simulations must be repeated for both non-nuclear and radionuclide air emissions. Furthermore, the methodology for calculating the dose must be done according to the latest international standards and NNR requirements.

7 REFERENCES

Areva (2007). UK EPR Safety, Security and Environmental Report - submission to UK Health and Safety Executive, Areva NP and EDF, 2007, <http://www.epr-reactor.co.uk/scripts/ssmod/publigen/content/templates/show.asp?P=139&L=EN>. Retrieved on 16 April 2008

Areva (2005) EPR - Areva brochure, Areva NP, May 2005, <http://www.areva-np.com/common/liblocal/docs/Brochure/EPR_US_%20May%202005.pdf>. Retrieved on 2 January 2008

Bagnold R A (1941). The Physics of Blown Sand and Desert Dunes, Methuen, New York, 265 pp.

Ball F. K., (1960). Control of inversion height by surface heating. Quart. J. Roy. Meteor. Soc., 86, 983–994.

Clemence, B.S.E. (1992). An attempt at estimating solar radiation at South African sites which measure air temperature only. South African Journal of Plant and Soil, 9, 40-42.

Dayan U., Shenhav, R. and Graber M., (1988). The spatial and temporal behavior of the mixed layer in Israel. J. Appl. Meteor., 27, 1382–1394.

DME (2006) Regulation R 388 (28 April 2006) in terms of section 36, read with section 47 of the National Nuclear Regulator Act (Act No. 47 of 1999) on Safety Standards and Regulatory Practices.

Draxler R R and Hess G D (1997). Description of the Hysplit_4 modelling System, NOAA, Technical Memorandum, ERL ARL-224, December, 24p.

EA (2008). Generic Design Assessment of New Nuclear Power Plant Designs, Environment Agency, Bristol, UK

Gifford, FA. (1962). Uses of Routine Meteorological Observations for Estimating Atmospheric Dispersion. Nuclear Safety.

Goliger A M. and Retief J V (2007) Severe wind phenomena in Southern Africa and the related damage, Journal of Wind Engineering and Industrial Aerodynamics, Volume 95, p 1065-1078

Gryning S. E., Holtslag A. M. M, Irwin J. S., and Sivertsen B., (1987). Applied dispersion modeling based on meteorological scaling parameters. Atmos. Environ., 21, 79–89.

Heinemann, K., Vogt, K.J. (1980), Statistical studies on the limitation of short-time releases from nuclear facilities, Congress of the International Radiation Protection Association (Proc. 5th Congr. Jerusalem, 1980), Vol. 2, IRPA, Washington, DC (1980), 67–70.

Holtslag A. A. M., and Van Ulden A. P., (1983). A simple scheme for daytime estimates of the surface fluxes from routine weather data. J. Climate Appl. Meteorol., 22, 517–529.

IAEA (1980). Atmospheric Dispersion in Nuclear Power Plant Siting: A Safety Guide, Safety Series No. 50-SG-S3, International Atomic Energy Agency, Vienna.

IAEA (1996). Food And Agriculture Organization Of The United Nations, International Atomic Energy Agency, International Labour Organisation, Oecd Nuclear Energy Agency, Pan American Health Organization, World Health Organization, International Basic Safety Standards for Protection against Ionizing Radiation and for the Safety of Radiation Sources, Safety Series No. 115, International Atomic Energy Agency, Vienna.

IAEA (2000). Regulatory Control of Radioactive Discharges to the Environment, Safety Standards No. WS-G-2.3, International Atomic Energy Agency, Vienna.

IAEA (2001). Generic Models For Use In Assessing The Impact Of Discharges Of Radioactive Substances To The Environment, Safety Reports Series No. 19, International Atomic Energy Agency, Vienna.

ICRP (1990) Recommendations of the International Commission on Radiological Protection, Publication 60, International Commission On Radiological Protection, Pergamon Press, Oxford and New York (1991).

ICRP (1996). Age-Dependent Doses to the Members of the Public from Intake of Radionuclides Part 5, Compilation of Ingestion and Inhalation Coefficients, Publication 72, International Commission On Radiological Protection, Pergamon Press, Oxford and New York.

Kalthoff N., Binder H. J., Kossman M., Vögtlin R., Corsmeier U., Fiedler F., and Schlager H., (1998). Temporal evolution and spatial variation of the boundary layer over complex terrain. Atmos. Environ., 32, 1179–1194.

Kruger A C (2002). Climate of South Africa: Surface Winds, South African Weather Services, WS43, Pretoria

Le Roux J J (1983), Climate of South Africa. Part 11: Extreme Values of rainfall, temperature and Wind for Selected Return Periods, WB 36, Weather Bureau, Department of Transport, Pretoria, 31 pp.

Marticorena B and Bergametti G (1995). Modeling the Atmospheric Dust Cycle: 1. Design of a Soil-Derived Dust Emission Scheme. Journal of Geophysical Research, 100, 16 415 - 16 430.

McElroy J. L., and Smith T. B., (1991). Lidar description of mixing-layer thickness characteristics in a complex terrain/coastal environment. J. Appl. Meteor., 30, 585–597.

Nakicenovic, N. *et al* (2000). Special Report on Emissions Scenarios: A Special Report of Working Group III of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, U.K., 599 pp.

Nicholson, K. W. (1987). Deposition of caesium to surfaces of buildings. Radiat. Prot. Dos., 21, 37-42.

NNR (1999a). National Nuclear Regulator Act, 1999.

NNR (1999b). R.388 National Nuclear Regulator Act (47/1999): Regulations: Safety Standards and Regulatory Practices.

NNR (2007). Requirements Document RD-0018: Basic licensing requirements for the pebble bed modular reactor. National Nuclear Regulator, Centurion.

Oke T R (1987). Boundary Layer Climates, Matheun, London

Pasquill, F. (1961). The Estimation of the Dispersion of Windborne Materials. Meteorological Magazine No. 90.

Pfeffer, W.T., Harper, J.T. and O'Neel, S.O. (2008) Kinematic Constrains on Glacier Contributions to 21st-Century Sea-Level Rise. Science, 321 no 5894, 1340-1343.

Radiological Environmental Survey (2008). Koeberg Nuclear Power Station: Radiological Environmental Survey – Annual Report 2008, Eskom Generation.

Rautenbach, C.J.deW., Mphepya, J. (2005) Observed rainfall trends over South Africa: 1960 – 2001. Research report submitted to ESKOM. Report no: RES/RR/04/25332, 22pp.

Reichler T and Kim J (2008). How Well Do Coupled Models Simulate Today's Climate? Bulletin of the American Meteorological Society, vol. 89, iss. 3, 303-331.

Roed, J. (1987). Dry deposition in urban and rural areas in Denmark. Radiat. Prot. Dos., 21, 33-36.

SAWS (1991). South African Weather Service Publication. 1991. Caelum - A History of Notable Weather Events in South Africa 1550 - 1990.

SAWS (1996) Regional Description of the Weather and Climate of South Africa: The Weather and Climate of the Extreme South-Western Cape, Department of Environmental Affairs and Tourism.

Schulze B R (1986). Climate of South Africa, WB 40, Weather Bureau, Department of Transport, Pretoria, 330 pp.

Schulze R E (1997). South African Atlas of Agrohydrology and -climatology, Department of Agriculture and Engineering, University of Natal, Pietermaritzburg, 276 pp.

Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.) (2007). IPCC Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [IPCC]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 996 pp.

US EPA (1984) INPUFF – A Single Source Gaussian Puff Dispersion Algorithm, User's Guide

US EPA (1989). User's Guide to the Complex Terrain Dispersion Model Plus Algorithms for Unstable Situations (CTDMPLUS), Volume 1, Model Description and User Instructions.

US EPA (1995). Air Pollution Emission Factors (AP-42) as contained in the AirCHIEF (AIR Clearinghouse for Inventories and Emission Factors), US Environmental Protection Agency, Research Triangle Park, North Carolina.

Van Heerden, J. and Hurry, L (1987) Southern Africa's weather patterns: an introductory guide. Arcadia Books, P.O.Box 6361, Pretoria, 0001, South Africa. ISBN 0 86817 045 3, pp 95.

Zhang J. S., and Rao S. T., (1999). The role of vertical mixing in the temporal evolution of ground-level ozone concentrations. J. Appl. Meteor., 38, 1674–1691

8 APPENDICES

8.1 APPENDIX A: AIR QUALITY ASSESSMENT CRITERIA

This section contains a summary of air quality limits used internationally and locally.

8.1.1 Non-Nuclear Pollutants

This section contains a summary of air quality limits used internationally and locally.

(a) Sulfur Dioxide

Ambient air quality guidelines and standards issued for various countries and organisations for sulfur dioxide are given in Table 8-1.

Table 8-1: Ambient air quality guidelines and standards for sulfur dioxide for various countries and organisations

Authority	Maximum 10-minute Average (µg/m³)	Maximum 1-hourly Average (µg/m³)	Maximum 24-hour Average (µg/m³)	Annual Average Concentration (µg/m³)
SA standards (Air Quality Act)	500(a)	350(a)	125(a)	50
RSA SANS limits (SANS:1929,2004)	500(b)	350(b)	125(b)	50
Australian standards	-	524(c)	209(c)	52
European Community (EC)	-	350(d)	125(e)	20(f)
World Bank	-	-	125(g)	50(g)
United Kingdom	266(h)	350(i)	125(j)	20(k)
United States EPA	-	-	365(l)	80
World Health Organisation (2000)	500(m)		125(m)	50(m) 10-30(m)
World Health Organisation (2005)	500(o)		20(o)	(o)

NOTES:
(a) Permissible frequencies of 526, 88 and 4 exceedances per year for 10-minute, hourly and daily averages
(b) Limit values only.
(c) Australian ambient air quality standards. (http://www.deh.gov.au/atmosphere/airquality/standards.html). Not to be exceeded more than 1 day per year. Compliance by 2008.
(d) EC First Daughter Directive, 1999/30/EC (http://europa.eu.int/comm/environment/air/ambient.htm). Limit to protect health, to be complied with by 1 January 2005 (not to be exceeded more than 24 times per calendar year).

(e) EC First Daughter Directive, 1999/30/EC (http://europa.eu.int/comm/environment/air/ambient.htm). Limit to protect health, to be complied with by 1 January 2005 (not to be exceeded more than 3 times per calendar year).
(f) EC First Daughter Directive, 1999/30/EC (http://europa.eu.int/comm/environment/air/ambient.htm). Limited value to protect ecosystems. Applicable two years from entry into force of the Air Quality Framework Directive 96/62/EC.
(g) World Bank, 1998. Pollution Prevention and Abatement Handbook. (www.worldbank.org). Ambient air conditions at property boundary.
(h) UK Air Quality Objective for 15-minute averaging period (www.airquality.co.uk/archive/standards/php). Not to be exceeded more than 35 times per year. Compliance by 31 December 2005.
(i) UK Air Quality Objective (www.airquality.co.uk/archive/standards/php). Not to be exceeded more than 24 times per year.
(j) UK Air Quality Objective (www.airquality.co.uk/archive/standards/php). Not to be exceeded more than 3 times per year.
(k) UK Air Quality Objective (www.airquality.co.uk/archive/standards/php).
(l) US National Ambient Air Quality Standards (www.epa.gov/air/criteria.html). Not to be exceeded more than once per year.
(m) WHO Guidelines for the protection of human health (WHO, 2000).
(n) Represents the critical level of ecotoxic effects (issued by WHO for Europe); a range is given to account for different sensitivities of vegetation types (WHO, 2000).
(o) WHO Air Quality Guidelines, Global Update, 2005 – Report on a Working Group Meeting, Bonn, Germany, 18-20 October 2005. Documents new WHO guidelines primarily for the protection of human health. The 10-minute guideline of 500 µg/m³ published in 2000 remains unchanged but the daily guideline is significantly reduced from 125 µg/m³ to 20 µg/m³ (in line with the precautionary principle). An annual guideline is given at not being needed, since “compliance with the 24-hour level will assure lower levels for the annual average”.

(b) Oxides of Nitrogen

The standards and guidelines of most countries and organisations are given exclusively for NO_2 concentrations. South Africa's NO_2 standards are compared to various widely referenced foreign standards and guidelines in Table 8-2.

Table 8-2: Ambient air quality guidelines and standards for nitrogen dioxide for various countries and organisations

Authority	Maximum 1-hourly Average (µg/m³)	Maximum 24-hour Average (µg/m³)	Maximum 1-month Average (µg/m³)	Annual Average Concentration (µg/m³)
SA standards (Air Quality Act)	200(a)	-	-	40
RSA SANS limits (SANS:1929,2004)	200(b)	-	-	40(b)
Australian standards	226(c)			56
European Community (EC)	200(d)	-	-	40(e)
World Bank	-	150 (as NOx)(f)	-	-
United Kingdom	200(g)	-	-	40(h) 30(i)
United States EPA	-	-	-	100(j)
World Health Organisation (2000, 2005)	200(k)		-	40(k)

NOTES :
(a) Permissible frequencies of 88 exceedances per year for the hourly average.
(b) Limit values only.

(c) Australian ambient air quality standards. (http://www.deh.gov.au/atmosphere/airquality/standards.html). Not to be exceeded more than 1 day per year. Compliance by 2008.
(d) EC First Daughter Directive, 1999/30/EC (http://europa.eu.int/comm/environment/air/ambient.htm). Averaging times represent the 98th percentile of averaging periods; calculated from mean values per hour or per period of less than an hour taken throughout the year; not to be exceeded more than 18 times per year. This limit is to be complied with by 1 January 2010.
(e) EC First Daughter Directive, 1999/30/EC (http://europa.eu.int/comm/environment/air/ambient.htm). Annual limit value for the protection of human health, to be complied with by 1 January 2010.
(f) World Bank, 1998. Pollution Prevention and Abatement Handbook. (www.worldbank.org). Ambient air conditions at property boundary.
(g) UK Air Quality Provisional Objective for NO2 (www.airquality.co.uk/archive/standards/php). Not to be exceeded more than 18 times per year.
(h) UK Air Quality Provisional Objective for NO2 (www.airquality.co.uk/archive/standards/php).
(i) UK Air Quality Objective for NOx for protection of vegetation (www.airquality.co.uk/archive/standards/php).
(j) US National Ambient Air Quality Standards (www.epa.gov/air/criteria.html).
(k) WHO Guidelines for the protection of human health (WHO, 2000). AQGs remain unchanged according to WHO (2005).

(c) Carbon Monoxide

The ambient air quality guidelines and other standards issued for various countries and organisations for carbon monoxide are given in Table 8-3.

Table 8-3: Ambient air quality guidelines and standards for carbon monoxide for various countries and organisations

Authority	Maximum 1-hourly Average(µg/m³)	Maximum 8-hour Average (µg/m³)
SA standards (Air Quality Act)	30 000(a)	10 000(a)
SA SANS limits (SANS:1929,2004)	30 000(b)	10 000(b)
Australian standards	-	10 000(c)
European Community (EC)	-	10 000(d)
World Bank	-	-
United Kingdom	-	10 000(e)
United States EPA	40 000(f)	10 000(f)
World Health Organisation	30 000(g)	10 000(g)

NOTES:
(a) Permissible frequencies of 88 and 11 exceedances per year for hourly and 8-hourly averages
(b) Limit values only.
(c) Australian ambient air quality standards.
(http://www.deh.gov.au/atmosphere/airquality/standards.html). Not to be exceeded more than 1 day per year.
(d) EC Second Daughter Directive, 2000/69/EC
(http://europa.eu.int/comm/environment/air/ambient.htm).
(e) UK Air Quality Objective (www.airquality.co.uk/archive/standards/php). Maximum daily running 8-hourly mean. Compliance by 31 December 2003.
(f) US National Ambient Air Quality Standards (www.epa.gov/air/criteria.html). Not to be exceeded more than one per year.
(g) WHO Guidelines for the protection of human health (WHO, 2000).

(d) Suspended Particulate Matter

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

The nasal openings permit very large dust particles to enter the nasal region, along with much finer airborne particulates. Larger particles are deposited in the nasal region by impaction on the hairs of the nose or at the bends of the nasal passages. Smaller particles (PM10) pass through the nasal region and are deposited in the tracheobronchial and pulmonary regions. Particles are removed by impacting with the wall of the bronchi when they are unable to follow the gaseous streamline flow through subsequent bifurcations of the bronchial tree. As the airflow decreases near the terminal bronchi, the smallest particles are removed by Brownian motion, which pushes them to the alveolar membrane (CEPA/FPAC Working Group, 1998; Dockery and Pope, 1994).

Air quality guidelines for particulates are given for various particle size fractions, including total suspended particulates (TSP), inhalable particulates or PM10 (i.e. particulates with an aerodynamic diameter of less than 10 µm), and respirable particulates of PM2.5 (i.e. particulates with an aerodynamic diameter of less than 2.5 µm). Although TSP is defined as all particulates with an aerodynamic diameter of less than 100 µm, and effective upper limit of 30 µm aerodynamic diameter is frequently assigned. PM10 and PM2.5 are of concern due to their health impact potentials. As indicated previously, such fine particles are able to be deposited in, and damaging to, the lower airways and gas-exchanging portions of the lung.

PM10 limits and standards issued nationally and abroad are documented in Table 8-4. In addition to the PM10 standards published in Schedule 2 of the Air Quality Act, the Act also includes standards for total suspended particulates (TSP), viz. a 24-hour average maximum concentration of 300 µg/m³ not to be exceeded more than three times in one year and an annual average of 100 µg/m³.

Table 8-4: Air quality standard for inhalable particulates (PM10).

Authority	**Maximum 24-hour Concentration (µg/m³)**	**Annual Average Concentration (µg/m³)**
SA standards (Air Quality Act)	120(a) 75(a)	50(a) 40(a)
RSA SANS limits (SANS:1929,2004)	75(b) 50(c)	40(d) 30(e)
Australian standards	50(f)	-
European Community (EC)	50(g)	40(h) 20(i)
World Bank (General Environmental Guidelines)	70(j)	50(j)
United Kingdom	50(k)	40(l)
United States EPA	150(m)	50(n)
World Health Organisation	(o)	(o)

Notes:
(a) Permissible frequencies of exceedance of 120 µg/m³ daily average of 4 until 31 December 2014. From 1 January 2015, limit value reduces to 75 µg/m³ with permissible number of exceedances of 4 per year. Annual limit value reduces from 50 µg/m³ to 40 µg/m³ after 1 January 2015.
(b) Limit values only
(c) Target values only
(d) Limit value. Margin of tolerance and date by which limit value should be complied with not yet set.
(e) Target value. Date by which limit value should be complied with not yet set.

(f) Australian ambient air quality standards. (http://www.deh.gov.au/atmosphere/airquality/standards.html). Not to be exceeded more than 5 days per year. Compliance by 2008.
(g) EC First Daughter Directive, 1999/30/EC (http://europa.eu.int/comm/environment/air/ambient.htm). Compliance by 1 January 2005. Not to be exceeded more than 35 times per calendar year. (By 1 January 2010, no violations of more than 7 times per year will be permitted.)
(h) EC First Daughter Directive, 1999/30/EC (http://europa.eu.int/comm/environment/air/ambient.htm). Compliance by 1 January 2005
(i) EC First Daughter Directive, 1999/30/EC (http://europa.eu.int/comm/environment/air/ambient.htm). Compliance by 1 January 2010
(j) World Bank, 1998. Pollution Prevention and Abatement Handbook. (www.worldbank.org). Ambient air conditions at property boundary.
(k) UK Air Quality Objectives. www.airquality.co.uk/archive/standards/php. Not to be exceeded more than 35 times per year. Compliance by 31 December 2004
(l) UK Air Quality Objectives. www.airquality.co.uk/archive/standards/php. Compliance by 31 December 2004
(m) US National Ambient Air Quality Standards (www.epa.gov/air/criteria.html). Not to be exceeded more than once per year.
(n) US National Ambient Air Quality Standards (www.epa.gov/air/criteria.html). To attain this standard, the 3-year average of the weighted annual mean PM10 concentration at each monitor within an area must not exceed 50 µg/m³.
(o) WHO (2000) issues linear dose-response relationships for PM10 concentrations and various health endpoints. No specific guideline given.

During the 1990s the World Health Organisation (WHO) stated that no safe thresholds could be determined for particulate exposures and responded by publishing linear dose-response relationships for PM10 and PM2.5 concentrations (WHO, 2005). This approach was not well accepted by air quality managers and policy makers. As a result the WHO Working Group of Air Quality Guidelines recommended that the updated WHO air quality guideline document contain guidelines that define concentrations which, if achieved, would be expected to result in significantly reduced rates of adverse health effects. These guidelines would provide air quality managers and policy makers with an explicit objective when they were tasked with setting national air quality standards. Given that air pollution levels in developing countries frequently far exceed the recommended WHO air quality guidelines (AQGs), the Working Group also proposed interim targets (IT) levels, in excess of the WHO AQGs themselves, to promote steady progress towards meeting the WHO AQGs (WHO, 2005). The air quality guidelines and interim targets issued by the WHO in 2005 for particulate matter are given in Tables 2-2 and 2-3.

Table 8-5: WHO air quality guideline and interim targets for particulate matter (annual mean) (WHO, 2005)

Annual Mean Level	PM10 (µg/m³)	PM2.5 (µg/m³)	Basis for the selected level
WHO interim target-1 (IT-1)	70	35	These levels were estimated to be associated with about 15% higher long-term mortality than at AQG
WHO interim target-2 (IT-2)	50	25	In addition to other health benefits, these levels lower risk of premature mortality by approximately 6% (2-11%) compared to WHO-IT1
WHO interim target-3 (IT-3)	30	15	In addition to other health benefits, these levels reduce mortality risks by another approximately 6% (2-11%) compared to WHO-IT2

Annual Mean Level	PM10 (µg/m³)	PM2.5 (µg/m³)	Basis for the selected level
			levels.
WHO Air Quality Guideline (AQG)	20	10	These are the lowest levels at which total, cardiopulmonary and lung cancer mortality have been shown to increase with more than 95% confidence in response to PM2.5 in the American Cancer Society (ACS) study (Pope et al., 2002 as cited in WHO 2005). The use of the PM2.5 guideline is preferred.

Table 8-6: WHO air quality guideline and interim targets for particulate matter (daily mean) (WHO, 2005)

Annual Mean Level	PM10 (µg/m³)	PM2.5 (µg/m³)	Basis for the selected level
WHO interim target-1 (IT-1)	150	75	Based on published risk coefficients from multi-centre studies and meta-analyses (about 5% increase of short-term mortality over AQG)
WHO interim target-2 (IT-2)*	100	50	Based on published risk coefficients from multi-centre studies and meta-analyses (about 2.5% increase of short-term mortality over AQG)
WHO interim target-3 (IT-3)**	75	37.5	Based on published risk coefficients from multi-centre studies and meta-analyses (about 1.2% increase of short-term mortality over AQG)
WHO Air Quality Guideline (AQG)	50	25	Based on relation between 24-hour and annual levels

* 99th percentile (3 days/year)

** for management purposes, based on annual average guideline values; precise number to be determined on basis of local frequency distribution of daily means

(e) Dust Deposition

Foreign dust deposition standards issued by various countries are given in Table 8-7. It is important to note that the limits given by Argentina, Australia, Canada, Spain and the USA are based on annual average dustfall. The standards given for Germany are given for maximum monthly dustfall and therefore comparable to the dustfall categories issued locally. Based on a comparison of the annual average dustfall standards it is evident that in many cases a threshold of ~200 mg/m^2/day to ~300 mg/m^2/day is given for residential areas.

Table 8-7: Dust deposition standards issued by various countries

Country	Annual Average Dust Deposition Standards (based on monthly monitoring) (mg/m^2/day)	Maximum Monthly Dust Deposition Standards (based on 30 day average) (mg/m^2/day)
Argentina	133	Not Applicable
Australia	133 (onset of loss of amenity) 333 (unacceptable in New South Wales)	Not Applicable
Canada Alberta: Manitoba	179 (acceptable) 226 (maximum acceptable) 200 (maximum desirable)	Not Applicable
Germany	Not Applicable	350 (maximum permissible in general areas) 650 (maximum permissible in industrial areas)
Spain	200 (acceptable)	Not Applicable
USA: Hawaii Kentucky New York Pennsylvania Washington Wyoming	 200 175 200 (urban, 50 percentile of monthly value) 300 (urban, 84 percentile of monthly value) 267 183 (residential areas) 366 (industrial areas) 167 (residential areas) 333 (industrial areas)	Not Applicable

Locally dust deposition is evaluated according to the criteria published by the South African Department of Environmental Affairs (DEA) (formerly known as Department of Environmental Affairs and Tourism (DEAT)).

In terms of these criteria dust deposition is classified as follows:

SLIGHT	-	less than 250 mg/m²/day
MODERATE	-	250 to 500 mg/m²/day
HEAVY	-	500 to 1200 mg/m²/day
VERY HEAVY	-	more than 1200 mg/m²/day

The Department of Minerals and Energy (DME) uses the 1 200 mg/m²/day threshold level as an action level. In the event that on-site dustfall exceeds this threshold, the specific causes of high dustfall should be investigated and remedial steps taken.

"Slight" dustfall is barely visible to the naked eye. "Heavy" dustfall indicates a fine layer of dust on a surface, with "very heavy" dustfall being easily visible should a surface not be cleaned for a few days. Dustfall levels of > 2000 mg/m²/day constitute a layer of dust thick enough to allow a person to "write" words in the dust with their fingers.

A perceived weakness of the current dustfall guidelines is that they are purely descriptive, without giving any guidance for action or remediation (SLIGHT, MEDIUM, HEAVY, VERY HEAVY). It has recently been proposed (as part of the SANS air quality standard setting processes) that dustfall rates be evaluated against a four-band scale, as presented in Table 8-8. Proposed target, action and alert thresholds for ambient dust deposition are given in Table 8-9.

According to the proposed dustfall limits an enterprise may submit a request to the authorities to operate within the Band 3 ACTION band for a limited period, providing that this is essential in terms of the practical operation of the enterprise (for example the final removal of a tailings deposit) and provided that the best available control technology is applied for the duration. No margin of tolerance will be granted for operations that result in dustfall rates in the Band 4 ALERT.

Table 8-8: Bands of dustfall rates proposed for adoption

BAND NUMBER	BAND DESCRIPTION LABEL	DUST-FALL RATE (D) (mg m^{-2} day^{-1}, 30-day average)	COMMENT
1	RESIDENTIAL	D < 600	Permissible for residential and light commercial
2	INDUSTRIAL	600 < D < 1 200	Permissible for heavy commercial and industrial
3	ACTION	1 200 < D < 2 400	Requires investigation and remediation if two sequential months lie in this band, or more than three occur in a year.
4	ALERT	2 400 < D	Immediate action and remediation required following the first exceedance. Incident report to be submitted to relevant authority.

Table 8-9: Target, action and alert thresholds for ambient dustfall

LEVEL	DUST-FALL RATE (D) (mg m^{-2} day^{-1}, 30-day average)	AVERAGING PERIOD	PERMITTED FREQUENCY OF EXCEEDANCES

TARGET	300	Annual	
ACTION RESIDENTIAL	600	30 days	Three within any year, no two sequential months.
ACTION INDUSTRIAL	1 200	30 days	Three within any year, not sequential months.
ALERT THRESHOLD	2 400	30 days	None. First exceedance requires remediation and compulsory report to authorities.

8.1.2 Radionuclides

(a) Occupational Exposure

(i) General Dose Limits (Government Notice No. R 388 of 2006, DME 2006)

The dose limit means the value of the effective dose or equivalent dose to individuals from actions authorised by a nuclear installation licence, nuclear vessel license or certificate of registration that must not be exceeded.

The occupational exposure of any worker shall be so controlled that the following limits are not exceeded:

- An (average) effective dose of 20 mSv per year averaged over five consecutive years ;
- An (maximum) effective dose of 50 mSv in any single year;
- An equivalent dose to the lens of the eye of 150 mSv in a year; and
- An equivalent dose to the extremities (hands and feet) or the skin of 500 mSv in a year.
- In special circumstances, provided that the radiation protection in the action has been optimised as required of the regulations but occupational exposure still remain above the dose limit of 50 mSv in any single year, the Regulator may approve a temporary change in the dose limit subject to the agreement of the affected employees, through their representatives where appropriate, and provided that all reasonable efforts are being made to improve the working conditions to the point where compliance with the dose limits can be achieved. This temporary change shall not exceed five years and shall not be renewed.

(ii) Apprentices and Students

For the apprentices of 16 to 18 years of age who are training for employment involving exposure to radiation and for the students of age 16 to 18 who are required to use sources in the course of their studies, the occupational exposure shall be so controlled that the following are not exceeded:

- An (average) effective dose of 20 mSv per year averaged over five consecutive years ;
- An effective dose of 6 mSv in a year;
- An equivalent dose to the lens of the eye of 50 mSv in a year; and

- An equivalent dose to the extremities or the skin of 150 mSv in a year.

(iii) Women

The annual effective dose limit for women of reproductive capacity is the same as that which is generally specified for occupational exposure. Following declaration of pregnancy, a limit on the equivalent dose to the abdomen of 2 mSv for the remainder of the pregnancy applies.

(iv) Emergencies

In the event of an emergency or when responding to an accident, a worker who undertakes emergency measures may be exposed to a dose in excess of the annual dose limit for persons occupationally exposed:

- For the purpose of saving life or preventing serious injury;
- If undertaking actions intended to advert a large collective dose; or
- If undertaking actions to prevent the development of catastrophic conditions.

Under the circumstances, all reasonable efforts must be made to keep doses to the worker below twice the maximum annual dose limit. In respect to life-saving interventions, every effort shall be made to keep doses below ten times the maximum annual dose limit. In addition, workers undertaking interventions which may result in their doses approaching or exceeding ten times the annual dose limit may only do so when the benefits to others clearly outweighs their own risk.

(b) Exposure of Visitors and Non-occupational Exposed Workers at Sites

The annual *effective dose* limit for visitors to the sites and those not deemed to be occupationally exposed is 1 mSv. The annual *dose equivalent* limit for individual organs and tissues of such persons is 10 mSv.

(c) Public Exposure

- The maximum annual effective dose limit for members of the public from all authorised actions is 1 mSv.
- No action may be authorised which would give rise to any member of the public receiving a radiation dose from all authorised actions exceeding 1 mSv in a year.

In accordance with section 4.5.2 of the regulation R.388, the *dose constraint*[18] applicable to an average member of the critical group within the exposed population should not exceed 0.25 mSv (or 250 µSv) in a year from potential exposure from the site:

[18] "dose constraint" means a prospective and source-related restriction on the individual dose arising from the predicted operation of the authorised action which serves exclusively as a bound on the optimisation of radiation protection and nuclear safety:

(a) to limit the range of options considered in the optimisation process and
(b) to restrict the doses via all exposure pathways to the average number of the critical group, in order to ensure that the sum of the doses received by the individual from all controlled sources remains within the dose limit, and which, if found retrospectively to have been exceeded, should not be regarded as an infringement of regulatory requirements but rather as a call for the reassessment of the optimisation of radiation protection.

4.5.2.1 Where applicable in terms of the prior safety assessment, the optimisation of radiation protection must be subject to dose constraints specific to the authorised action, which must not exceed values that can cause the relevant dose limits to be exceeded and which will ensure as far as practicable that doses are restricted by application of the ALARA [As Low As Reasonably Achievable] *principle on a source-specific basis rather than by dose limits.*
4.5.2.2 For members of the public, the dose constraint applicable to the average member of the critical group within the exposed population is 0,25 mSv per year specific to the authorised action unless otherwise agreed by the Regulator on a case-by-case basis, taking into account the dose limit specified in Annexure 2 for exposure of members of the public from all sources.

(d) Public Exposure to Design Basis Accidents

A dose limit for events such as design basis accidents is not specified in Government Notice No. R 388 of 2006. The only reference to a dose limit associated with events that have a frequency of occurrence between one in one hundred years ($<10^{-2}$ per year) and one in one million years (10^{-6} per year) is found in the NNR Requirements Document RD-0018, which specifies an accumulated total individual design dose limit of 50 mSv per event (NNR, 2007).

8.2 APPENDIX B: EMISSION INVENTORIES

8.2.1 Construction Phase

The construction phase will comprise land clearing and site development operations. In order to determine the significance of the potential for impacts it is necessary to quantify atmospheric emissions and predicted airborne pollutant concentrations and dustfall rates occurring as a result of such emissions. The construction phase will comprise a series of different operations including site excavation and construction of the proposed nuclear power station. In addition, transportation of equipment and labour will also be associated with these operations. Emissions due to transportation activities will include particulate matter due to vehicle entrainment on paved and unpaved surfaces and gaseous emissions (i.e. sulphur dioxide, nitrogen dioxide, diesel particulates, etc) due to vehicle exhaust. In order to quantify the gaseous emissions from vehicle exhaust, detailed information on the vehicle type, engine capacity and the quantity of fuel are required. For the current study, this information was not available for assessment.

(a) Excavation

Excavation of the proposed nuclear power station site will take place during the construction phase for a period of eighteen months months. The following predictive equation, as provided by the US Environmental Protection Agency (US EPA), is used to estimate emissions from anticipated excavation operations:

$$E_{TSP} = 0.0016\frac{(U/2.2)^{1.3}}{(M/2)^{1.4}}$$

where,

E_{TSP}	=	Total Suspended Particulate emission factor (kg dust / t transferred)
U	=	mean wind speed (m/s)
M	=	material moisture content (%)

(b) Vehicle-Entrained Emissions from Unpaved Roads

Vehicle-entrained dust emissions from unpaved haul roads represent a significant source of fugitive dust. The force of the wheels of vehicles travelling on unpaved roadways causes pulverisation of surface material. Particles are lifted and dropped from the rotating wheels, and the road surface is exposed to strong air currents in turbulent shear with the surface. The turbulent wake behind the vehicle continues to affect the road surface once the vehicle has passed. The quantity of dust emissions from unpaved roads varies linearly with the volume of traffic. In addition to traffic volumes, emissions also depend on a number of parameters which characterise the condition of a particular road and the associated vehicle traffic, including average vehicle speed, mean vehicle weight, average number of wheels per vehicle, road surface texture, and road surface moisture (EPA, 1998).

Vehicle activity on the proposed nuclear power station during construction will result in potentially significant particulate emissions.

The unpaved road size-specific emission factor equation of the US-EPA, used in the quantification of emissions, is given as follows:

$$E = k(\frac{s}{12})^a(\frac{W}{3})^b$$

where,

E = emissions in lb of particulates per vehicle mile travelled (lb/VMT)
Note: 1 lb/VMT = 281.9 g/VKT (vehicle kilometres travelled)
k = particle size multiplier (dimensionless)
s = silt content of road surface material (%)
W = mean vehicle weight (tonnes)

The particle size multiplier in the equation (k) varies with aerodynamic particle size range and is given as 1.5 for PM10 and 4.9 for total suspended particulates (TSP). *a* and *b* are given as 0.9 and 0.45 respectively for PM10 and as 0.7 and 0.45 respectively for TSP.

(c) Vehicle-Entrained Emissions from Paved Roads

Use will be made of the paved roads from the Koeberg site entrance to the proposed nuclear power station site to transport labour and equipment to the site. The other two sites would also be paved were practically possible.

The paved road size-specific emission factor equation of the US-EPA, used in the quantification of emissions, is given as follows:

$$E = k(\frac{sL}{2})^{0.65}(\frac{W}{3})^{1.5} - C$$

Where,

E = particulate emission factor in grams per vehicle kilometre travelled (g/VKT)
k = particle size multiplier (dimensionless)
s = silt loading of road surface material (g/m²)
W = mean vehicle weight (tonnes)
C = emission factor for 1980's vehicle fleet exhaust, break wear and tire wear

The particle size multiplier in the equation (k) varies with aerodynamic particle size range and is given as 4.6 for PM10 and 24 for total suspended particulates (TSP). Generic US-EPA silt loading was used (7.4 g/m²) in the emission estimates. The emission factor for C is 0.1317 g/VKT for PM10 and TSP respectively.

(d) Wind Erosion of Exposed Areas

Individual sand grains are moved under the force of the wind in two distinct ways: saltation and surface creep. The primary method of sand movement is saltation. As wind moves over a sand deposit, it is able to pick up grains from the surface and give them a forward momentum, but the weight of the sand grains soon bring the grains back to the surface. If the surface is composed of coarse, immobile particles, such as pebbles, the sand grains will bounce directly off the hard surface and back into the air, where the wind will once again provide a forward momentum. These bouncing grains can move downwind at about half the speed of the wind. If the surface is composed of finer sand grains, however, a saltating sand grain will not bounce off the surface; rather, it will strike the sandy surface and bury itself. The impact will eject a second grain into the air to be blown downwind. This "splashing" form of saltation results in a slower rate of downwind movement than the bouncing motion on hard surfaces. Either process falls under the definition of saltation (Bagnold, 1941).

Saltation of sand grains along the surface accounts for about 75% of all sand movement by wind. The wind speed necessary to maintain saltation once it has begun is termed the "impact threshold" and defined by Bagnold (1941) as the velocity at which "the energy received by the average saltating grains becomes equal to that lost (by impact), so that motion is sustained." Like the fluid threshold, the impact threshold increases with increasing grain size.

The overall volume of sand moved has an exponential relationship with wind velocity, i.e. as wind speeds increase, the downwind rate of sand movement increases exponentially. Even during intense "sand storms," however, at maximum wind speeds and sand movement, saltating grains rarely exceed two metres in height (Fryberger et al., 1979). Due to an increased fluid threshold, heavier sand grains are rarely moved directly by wind pressure. Only intense storm winds can lift the heavier grains off the surface. Grains larger than one millimetre in diameter are generally moved by a second process called surface creep (Bagnold, 1941; Sharp, 1966). When saltating sand grains strike these heavy grains on the surface, they don't have enough energy to knock them into the air, but they do impart to the heavy grains a slight forward momentum along the surface. In this way, heavy sand grains up to two hundred times the mass of the saltating grains can be slowly moved downwind. Up to 25% of all wind-transported sand is moved by surface creep (Bagnold, 1941).

An hourly particulate emissions file was created for the areas exposed during construction. The calculation of an emission rate for every hour of the simulation period was carried out using the ADDAS model. This model is based on the dust emission model proposed by Marticorena and Bergametti (1995). The model attempts to account for the variability in source erodibility through the parameterisation of the erosion threshold (based on the particle size distribution of the source) and the roughness length of the surface.

In the quantification of wind erosion emissions, the model incorporates the calculation of two important parameters, viz. the threshold friction velocity of each particle size, and the vertically integrated horizontal dust flux, in the quantification of the vertical dust flux (i.e. the emission rate).

Dust mobilisation occurs only for wind velocities higher than the threshold value, and is not linearly dependent on the wind friction and velocity. The threshold friction velocity, defined as the minimum friction velocity required to initiate particle motion, is dependent on the size of the erodible particles and the effect of the wind shear stress on the surface. The threshold friction velocity decreases with a decrease in the particle diameter, for particles with diameters >60 µm. Particles with a diameter <60 µm result in increasingly high threshold friction velocities, due to the increasingly strong cohesion forces linking such particles to each other (Marticorena and Bergametti, 1995). The relationship between particle sizes ranging between 1 µm and 500 µm and threshold friction velocities (0.24 m/s to 3.5 m/s), estimated based on the equations proposed by Marticorena and Bergametti (1995), is illustrated in Figure 8-1.

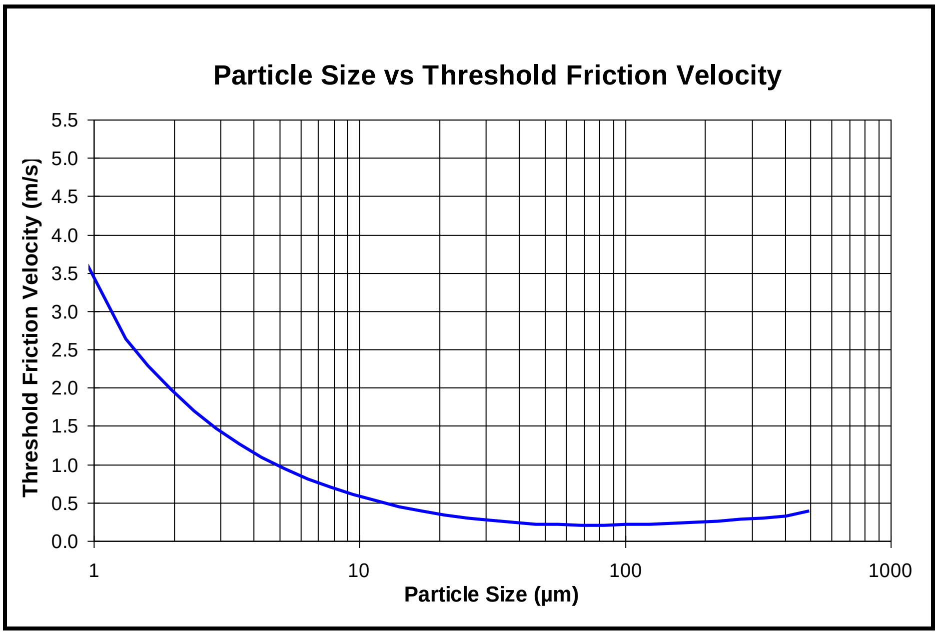


Figure 8-1: Relationship between particle sizes and threshold friction velocities using the calculation method proposed by Marticorena and Bergametti (1995).

8.2.2 Operational Phase

(a) Proposed Nuclear Power Stations: Routine Emissions

For the purposes of establishing an envelope of typical radionuclide emissions, the source terms for the Areva and Westinghouse designs were used in the simulations, as provided in Table 8-10.

The stack parameters are given in Table 8-11.

Table 8-10: Radionuclide emission rates for considered for the establishment of a source term envelope

Radionuclide	Emission Rate (GBq/annum)		
	EPR - Areva		AP1000 - Westinghouse
	Expected performance excluding operating contingencies	Maximum Release (includes operational occurrences)	
Ar-41	23.2	652.5	
Ba-140			0.00016
C-14	350	900	270
Co-58	0.000102	0.0867	0.0085
Co-60	0.0001204	0.10234	0.0032
Cr-51			0.00023
Cs-134	0.0000936	0.07958	0.00085
Cs-137	0.000084	0.0714	0.0013
H-3	500	3000	1800
I-131	0.0228	0.182	0.19
I-133	0.0272	0.2176	0.31
Kr-85	111.2	3127.5	3100
Kr-85m			24
Kr-87			19
Kr-88			27
Mn-54			0.00016
Nb-95			0.00093
Sr-89			0.0011
Sr-90			0.00044
Xe-131m	2.4	67.5	1400
Xe-133	504.8	14197.5	1300
Xe-133m			110
Xe-135	158.4	4455	440
Xe-135m			190
Xe-137			48
Xe-138			89
Zr-95			0.00037

Table 8-11: Stack parameters for two alternative nuclear power station designs (routine emissions)

Parameter	EPR (Areva)	AP1000 (Westinghouse)
Release Height	96 m	55.696 m
Stack Diameter	3 m	2.40136 m
Exit Gas Temperature	293 K	293 K
Exit Gas Velocity	5.8 m/s	0.4 m/s

Table 8-12: Measured emissions of radionuclides from Koeberg Nuclear Power Station

Nuclide	Emission Rates (Bq/a)																			
	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Ag-110m															6E+05				1E+06	
Ar-41	2E+11	1E+12	4E+13	8E+12	3E+12	2E+12	4E+12	2E+12	2E+11	6E+11	2E+11	3E+11	3E+12	1E+12	1E+11	6E+10	4E+10	2E+11	4E+10	7E+10
Co-58			6E+06													4E+05			3E+05	9E+04
Co-60						4E+05	8E+05				6E+05				4E+06	4E+06	1E+05	2E+05	4E+06	1E+06
Cs-134										1E+06	1E+07									
Cs-137										1E+06	2E+07				1E+06	6E+05	1E+06	4E+04	4E+06	1E+06
Fe-59															1E+06					
H-3	2E+11				2E+12	4E+12	6E+12	1E+13	8E+12	8E+12	5E+12	5E+12	8E+12	2E+13	6E+12	1E+13	8E+12	1E+13	1E+13	8E+12
I-131	7E+07	1E+08	3E+08	7E+08	3E+09	2E+09	1E+09	2E+09	1E+09	6E+08	4E+08	5E+08	2E+08	3E+08	7E+07	2E+08	3E+08	1E+09	5E+08	2E+08
I-132		4E+05	2E+08	1E+09	4E+09	1E+10	9E+08	2E+09	7E+08	2E+09	2E+09	3E+09	2E+09	2E+09	4E+08	5E+08	1E+09	2E+09	8E+08	2E+08
I-133	4E+07	5E+05	8E+08	2E+09	4E+09	8E+09	8E+08	2E+09	2E+09	2E+09	2E+09	2E+09	1E+09	2E+09	3E+08	4E+08	1E+09	1E+09	6E+08	4E+08
I-134		8E+04	1E+08	3E+09	5E+09	2E+10	2E+09	2E+09	6E+08	2E+09	3E+09	3E+09	2E+09	2E+09	4E+08	5E+08	1E+09	2E+09	9E+08	2E+08
I-135		2E+05	2E+08	2E+09	4E+09	1E+10	1E+09	2E+09	8E+08	2E+09	2E+09	3E+09	2E+09	2E+09	4E+08	6E+08	1E+09	2E+09	1E+09	3E+08
Kr-85		3E+09	9E+12	6E+11	8E+10	6E+12	7E+10	1E+13	8E+12	2E+11	6E+11	1E+12	4E+12	1E+10		1E+10		5E+12	4E+08	3E+10
Kr-85m	6E+07	5E+12	6E+12	2E+11	2E+12	5E+11	5E+10	2E+11	2E+11	2E+11	3E+11	4E+11	5E+12	3E+11	1E+10	8E+09	1E+09	2E+10	1E+09	1E+10
Kr-87	2E+06	2E+12	6E+12	1E+12	2E+12	5E+11	2E+10	3E+11	3E+11	2E+11	4E+11	7E+11	5E+12	1E+11	3E+10	4E+09	1E+09	2E+10	8E+09	9E+09
Kr-88	8E+06	3E+12	9E+12	2E+12	5E+12	1E+12	6E+10	7E+11	6E+11	4E+11	6E+11	1E+12	1E+13	1E+11	3E+10	1E+10	2E+09	2E+10	2E+09	6E+09
Mn-54															6E+05					
Na-24									6E+04		4E+04									
Sr-90																			2E+05	
Tc-99m						7E+00	2E+09										5E+06	1E+08	1E+08	
Xe-131m		1E+10	5E+12	2E+11	4E+11	2E+12	4E+11	1E+10	2E+11	2E+11	3E+11	5E+11	2E+11	7E+09	9E+08	8E+08	6E+08	6E+09	9E+10	3E+11
Xe-133	5E+09	4E+13	2E+14	2E+13	6E+13	5E+13	1E+13	1E+13	2E+13	5E+13	6E+13	7E+13	1E+14	1E+13	7E+11	4E+11	1E+11	1E+12	9E+10	2E+13
Xe-133m	3E+07	4E+11	3E+12	2E+11	1E+12	4E+11	4E+10	5E+10	1E+11	7E+11	5E+11	7E+11	3E+12	1E+10	2E+09	7E+09	2E+09	7E+09	2E+09	1E+11
Xe-135	4E+08	9E+12	4E+13	7E+12	1E+13	4E+12	1E+12	2E+12	2E+12	3E+12	3E+12	6E+12	3E+13	3E+12	2E+11	1E+11	2E+10	1E+11	2E+10	1E+12
Xe-135m			7E+12	6E+12	2E+12	4E+12	3E+12	2E+12	1E+12	7E+11	6E+11	2E+12	9E+12	2E+12	7E+10	2E+10	6E+09	3E+10	4E+07	2E+10
Xe-138			2E+12	2E+12	3E+12	1E+12			3E+11	4E+10	6E+11	2E+12	4E+12	4E+11	1E+11	2E+10	5E+09	1E+11		3E+10

Table 8-13: Design Basis Accident radionuclide emission rates

Incidents	Duration (hours)	Release Height
Main Steam Line Break Outside Containment (BWR and PWR) [initiated iodine spike]	96	Ground Level
Main Steam Line Break Outside Containment (BWR and PWR) [pre-existing iodine spike]	96	Ground Level
Reactor Coolant Pump Locked Rotor Accident (PWR)	1.5	Ground Level
Reactor Coolant Pump Locked Rotor Accident (PWR)	8	Ground Level
Control Rod Ejection (PWR)	720	Ground Level
Steam Generator Tube Rupture (PWR) [initiated iodine spike]	24	Ground Level
Steam Generator Tube Rupture (PWR) [pre-existing iodine spike]	24	Ground Level
Failure of Small Lines Carrying Primary Coolant Outside Containment (BWR and PWR)	0.5	Ground Level
Large-Break Loss-of-Coolant Accident (BWR and PWR)	720	Ground Level
Fuel Handling Accident (BWR and PWR)	2	Ground Level
Large Break LOCA - Cumulative Activity Release To The Plant Environment	168	Stack Release
Loss Of Primary Coolant Outside The Containment - Cumulative Activity Release To The Plant Environment	6	Stack Release
Leak In The Gaseous Waste Processing System, Cumulative Activity Release To The Plant Environment	3	Stack Release
Leak Of A System In The Waste Building, Activity Release To The Environment	1	Stack Release
Steam Generator Rupture Of 2 Tubes, Cumulative Activity Release To The Plant Environment	1	Ground Level
Fuel Handling Accident - Cumulative Activity Release To The Plant Environment	167.1	Stack Release
Loss Of Condenser Vacuum, Cumulative Activity Release To The Plant Environment	1	Ground Level
Damage Of Systems After Earthquake – Cumulative Activity Release To The Plant Environment	24	Ground Level

(b) Proposed Nuclear Power Stations: Accidental Releases

Typical design basis accident scenarios are described Table 8-13. These scenarios were provided by Areva and Westinghouse as design basis accidents. Radionuclide emission rates for each of the scenarios were provided and included the following nuclides:

Ag-110m	Nb-95, Nb95m
Am-241	Nd-147
Ar-41	Np-239
Ba-139, Ba-140	Pr-143
Ce-141, Ce-143, Ce-144	Pu-238, Pu-239, Pu-240, Pu-241
Cm-242, Cm-244	Rb-86, Rb-88, Rb-89
Co-58, Co-60	Rh-103m, Rh-105, Rh-106m
Cr-51	Ru-103, Ru-105, Ru-106
Cs-134, Cs-136, Cs-137, Cs-138	Sb-127, Sb-129
Fe-59	Sr-89, Sr-90, Sr-91, Sr-92
I-130, I-131, I-132, I-133, I-134, I-135	Tc-99m
Kr-83m, Kr-85, Kr-85m, Kr-87, Kr-88, Kr-89	Te-127, Te-127m, Te-129, Te-129m, Te-131, Te-131m. Te-132, Te-133, Te-133m, Te-134
La-140, La-141, La-142	Xe-131m, Xe-133, Xe-133m, Xe-135, Xe-135m, Xe-137, Xe-138
Mn-54	Y-90, Y-91, Y-92, Y-93, Y-95
Mo-99	Zr-95, Zr-97

(c) Existing Koeberg Nuclear Power Stations

Table 8-12 is a summary of historical measurements made at Koeberg. The vent characteristics for Koeberg are provided in Table 8-14.

Table 8-14: Stack parameters for the current Koeberg Nuclear Power Station

Parameter	Koeberg
Release Height	54 m
Stack Diameter	2.7 m
Exit Gas Temperature	298 K
Exit Gas Velocity	17.45 m/s

(d) Proposed Pebble Bed Modular Reactor Demonstration Power Plant

At the time of the investigation, the PBMR DPP was still considered for construction a Koeberg. The radiation emission releases for PBMR DPP were provided by ARCUS GIBB personnel. Radionuclide emissions for continuous PBMR releases are given in Figure 8-2. Both “design estimates” and the “best estimates” are provided in the figures. The “design estimates” are the maximum specified emissions, whereas the “best estimates” are the more likely emissions.

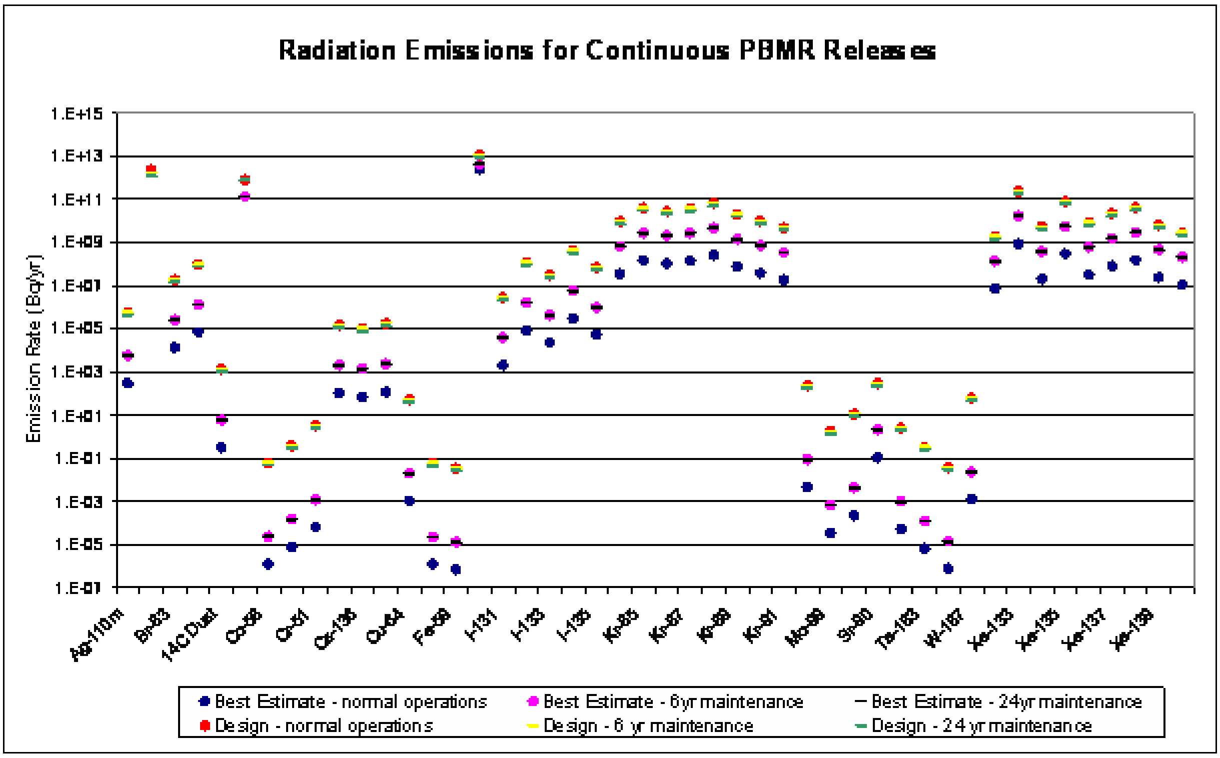


Figure 8-2: Radionuclide emission rates for the proposed PBMR DPP

The radionuclide emission rate used in the assessment for the PBMR DPP is based on a maximum design emission rate. As part of the licensing process, however, the National Nuclear Regulator (NNR) will approve a maximum allowable annual radionuclide emission rate for operation, which could be the same or lower. The impacts reported in this assessment therefore constitute a conservative estimate.

The stack parameters for the proposed PBMR DPP are summarised in Table 8-15.

Table 8-15: Stack parameters for the proposed PBMR DPP

Parameter	Koeberg
Release Height	75 m
Stack Diameter	1.2 m
Exit Gas Temperature	300 K
Exit Gas Velocity	16 m/s

8.3 APPENDIX C: TIBL DISPERSION MODELLING

Characterising the structure of the atmospheric boundary layer (ABL) and its spatial variation is of particular importance for understanding the mechanism of dispersion of pollution (Gryning *et al.* 1987). The vertical mixing in this turbulent layer, adjacent to the earth's surface and specifically its depth is a critical parameter in determining air pollution concentrations near the ground (Zhang and Rao 1999). The variation of its depth is governed by larger-scale (e.g., synoptic) vertical motion (Dayan et al. 1988), surface heating (Ball 1960; Holtslag and Van Ulden 1983), horizontal advection determined by the strength of the sea breeze in coastal areas (McElroy and Smith

1991), local terrain (Kalthoff *et al.* 1998), and the intensity of the subsiding atmospheric layer capping the mixed layer, characterized by the virtual temperature gradient within this stable layer.

The AERMOD dispersion model is not able to take coastal atmospheric stability conditions into account. ADMS on the other hand is able to model these effects but cannot take topographical influences into account simultaneously when making this calculation. Figure 8-3 provides a comparison of the ADMS modelling results (using the coastline module) with the AERMOD modelling (excluding formation of the coastal thermal internal boundary layer, but taking topography into account).

During night-time conditions, the ADMS model is less conservative with smaller areas of impact over the sea (due to the land breeze). In spite of not being able to take topography into account, ADMS shows higher maximum concentrations over land due to the thermal internal boundary layer. The impacts over the land are nonetheless, similar with the predicted impacts from the AERMOD model, apart from the south western region. Impacts due to topographical effects along these elevations are clearly indicated with the AERMOD model that is absent from the ADMS modelling results.

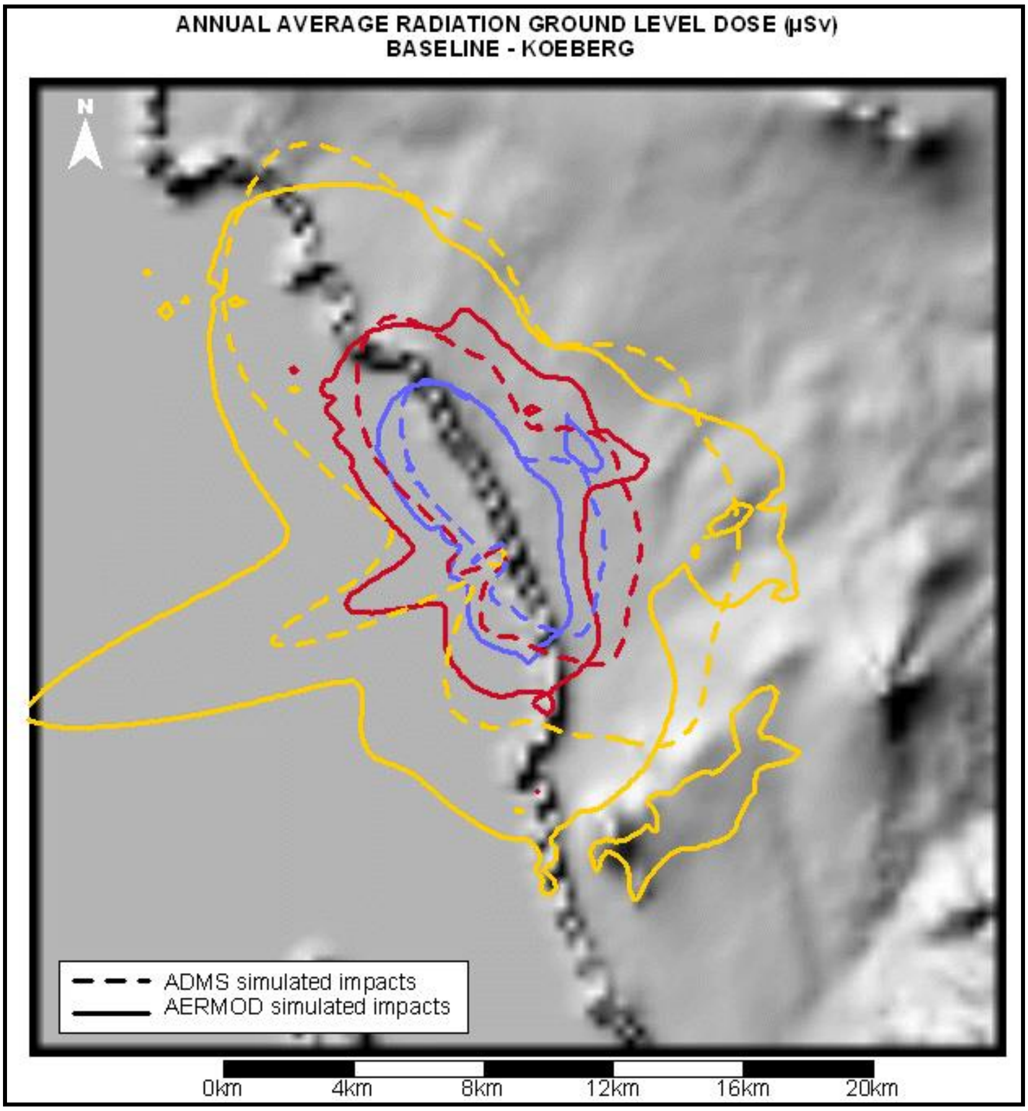


Figure 8-3: ADMS coastline modelling with reference to AERMOD modelling

8.4 APPENDIX D: CONSTRUCTION MITIGATION MANAGEMENT CHECKLIST

Potential dust or pollution source	Priority (high, medium, low)	Control Measure	Responsibility	Action taken if failed
Pre-site preparation				
Open ground				
Dust dispersion outside site boundary				
Vehicle emissions and haul routes				
Unpaved haul routes				
Dirty vehicles				
Road sweepers				
Road edges and verges				
Use of major traffic routes				
Re-suspension of road dust				
Visible exhaust smoke				
Lack of maintenance				
Idling and operation				
Exhaust height				
Direction of exhaust				
Location of plant				
Transport of fine materials				
Mobile crushing plant and cement batching				
Emissions from plant				
Fine cement powder				
Processing aggregates				
Mixing cement and other materials				
Material Handling				
Excavations				

Potential dust or pollution source	Priority (high, medium, low)	Control Measure	Responsibility	Action taken if failed
Earthworks				
Transfer of fine materials				
Loading material on chutes and skips				
Stockpiling/recycling				
Sweeping				
Construction activities				
Disc cutting or grinding				
Scabbling				
Sand blasting				
Material mixing				
Welding				
Demolition activities				
Blasting				
Removal of materials from site				
Stripping buildings				
Storage				
Fugitive emissions from stockpile in wind				
Material handling				
Location of stockpile or storage				
Height and gradient of stockpile				
Dealing with particularly dry and/or windy weather conditions				
Disposal				
Burning				

Potential dust or pollution source	Priority (high, medium, low)	Control Measure	Responsibility	Action taken if failed
Dust on roads/outside site				
Accidental spillages				
Cleaning up				
Removal of materials from site				
Crushing of material for re-use or disposal				
Incinerator				
Run-off water and mud				
Hazardous materials/contaminants				
Biological materials				
Asbestos-containing materials				
Contaminated land				
Volatile organic compounds/vapours				

8.5 APPENDIX E: AIRBORNE PARTICULATE MONITORING GUIDE

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

8.5.1 Filter-based Monitors

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

8.5.2 Filter-based, Off-line Samplers (SFUs, Sequential Samplers)

Stacked filter units and sequential air samplers are most frequently used when elemental, ionic and/or carbon analyses are required of the measured particulates. Filters are required to be weighed prior to their being loaded in the sampler for exposure in the field. Following exposure the filters are removed are reweighed in a lab to determine the particulate concentration. The filters may then be sent for elemental (etc.) analysis. Teflon-membrane filters are commonly used for mass and elemental analysis.

Figure 8-4: Partisol-Plus sequential air sampler.

Sequential air samplers with sequential dichotomous configurations splits the PM10 sample stream into its fine (PM2.5) and coarse (particles between 2.5 and 10 µm in size) fractions - collecting the fine and coarse mode particulates simultaneously on two different filters. Certain of these systems (e.g. Partisol-Plus Air Samplers, Figure 8-4) have capacities of up to 16 filter cassettes with an automatic filter exchange mechanism. (Filter changes can be triggered on a temporal basis or based on wind direction.) Once the 16 filters have been exposed, the filters would require collection and replacement.

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

8.5.3 Filter-based, On-line Samplers (TEOM, BAM)

The TEOM is operates by continuously measuring the weight of particles deposited onto a filter. The filter is attached to a hollow tapered element which vibrates at its natural frequency of oscillation - as particles progressively collect on the filter, the frequency changes by an amount proportional to the mass deposited. As the airflow through the system is regulated, it is possible to determine the concentration of particulates in the air. The filter requires changing periodically, typically every 2 to 4 weeks, and the instrument is cleaned whenever the filter is changed. Different inlet arrangements are used to configure the instrument. TEOMs can monitor PM10, PM2.5, PM1 and TSP continuously. Data averages and update intervals include: 5-minute total mass average (every 2 seconds), 10-minute rolling averages (every 2 seconds), 1-hour averages, 8-hour averages, 24-hour averages (etc.). The TEOM has a minimum detection limit of 0.01 µg/m3.

Beta attenuation monitors collect particulates on a filter paper over a specified cycle time. The attenuation of beta particles through the filter is continuously measured over this time. BAMs give real-time measurement of TSP, PM10 or PM2.5 depending on the inlet arrangement. At the start of the cycle, air is drawn through a glass fibre filter tape, where the particulates deposit. Beta particles that are emitted from either a C14 or a K85 sources are attenuated by the particles collecting on the filter. The radiation passing through the tape is detected by a scintillator and photomultiplier assembly. A reference measurement is made through a clean portion of the filter, either during or prior to the accumulation of the particles - the measurement enables baseline shifts to be corrected for.

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

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

The TEOM is US-EPA approved (EQPM-1090-079) as an equivalent method for measuring 24-hour average PM10 concentrations in ambient air quality. It represents the only continuous monitor which meets the California Air Resources Board acceptance criteria for 1-hour mass concentration averages. TEOM instrumentation also has German TÜV approval for TSP measurements. Not all beta gauges are US-EPA approved, with only the Andersen (FAG-Kigelfischer, Germany) and Wedding beta monitor having been approved.

The performance of the TEOM ad BAM monitors are compared in Table 8-16. The TEOM tends to perform better than BAMs in many respects, particularly with regard to the precision of measurements made. An additional advantage of the TEOM (14000 series) is the optional inclusion of the ACCU system. This system allows for conditional sampling by time/date, particulate concentration and/or wind speed and direction. The application of the TEOM in combination with the ACCU system could therefore allow for the assessment of an operation's contribution to particulate concentrations occurring at a site on an on-line real-time basis.

Table 8-16: Comparison of TEOM and BAM performance.

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

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

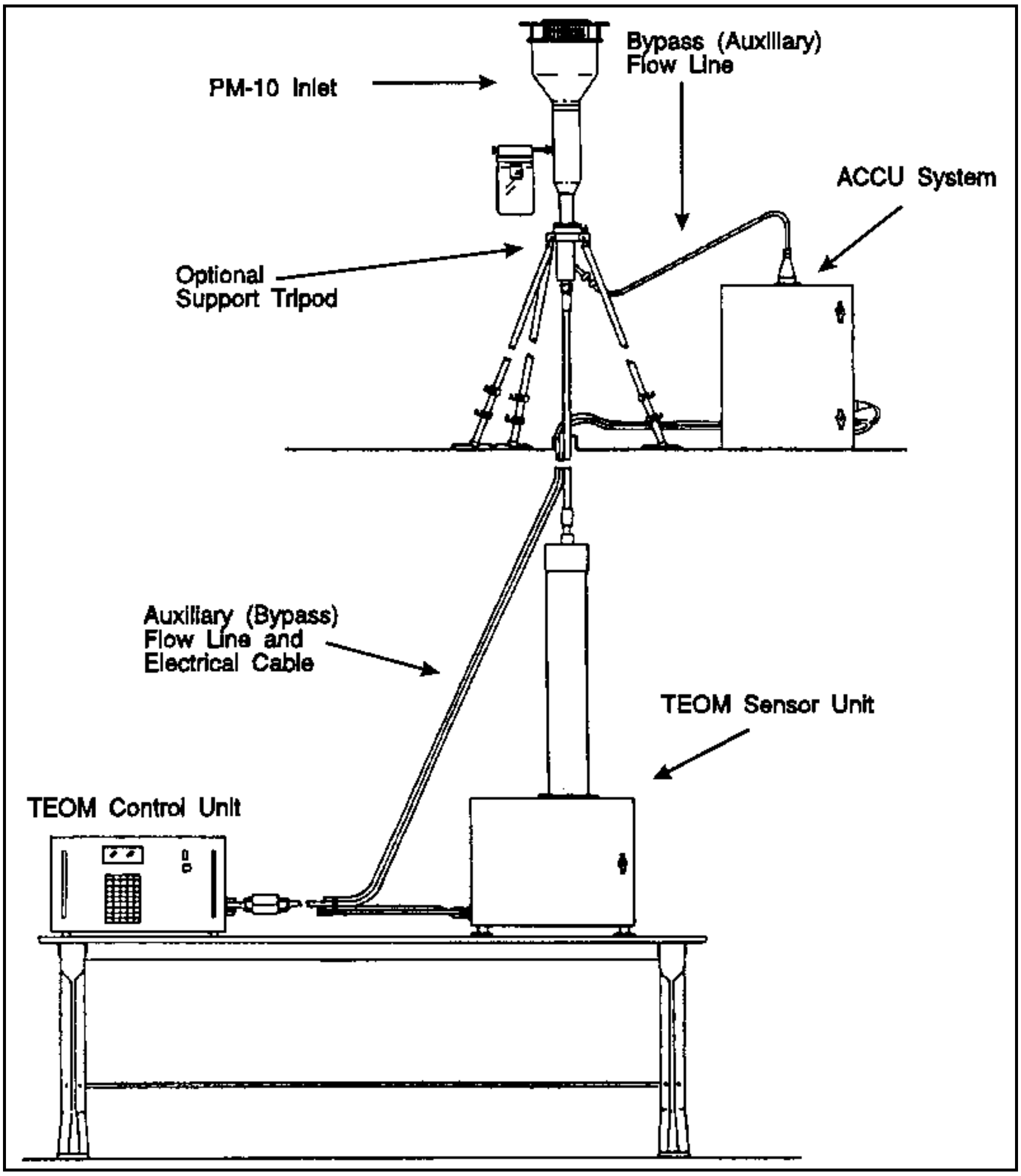


Figure 8-5: TEOM sampler linked to the ACCUTM conditional sampling system.

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

8.5.4 Non-filter-based Monitors

Locally-supplied, real-time but non-filter based monitors include the TSI DustTrak, the DustScan Sentinel Aerosol Monitor and the Topas Dust Monitor. Several of these monitors can be solar-powered negating the need for selecting a site with power access. Such monitors measures particle concentrations corresponding to various size fractions, including PM10, PM2.5 and PM1.0, and comprise many of the benefits of the TEOM and BAM monitors including:

- Continuous, near-real-time aerosol mass monitoring,
- A choice of averaging times from 1 minute to 24 hours,
- Limited operator intervention, and
- Minimal filter handling.

8.5.5 Data Transfer Options

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

- Downloaded intermittently from the instrument - PC link cable required
- Real-time, continuous transfer via telemetry - telemetry control unit required
- Near real-time, intermittent transfer via radio link - requires transmitter & license to use frequency
- Continuous download via satellite

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

8.6 APPENDIX F: AVAILABLE METEOROLOGICAL LITERATURE

The following list of literature on meteorological conditions at the three sites has been consulted in the assessment.

8.6.1 Duynefontein Site

Specific SAWS reports of relevance include:

- South African Weather Service Publication. 1991. Caelum - A History of Notable Weather Events in South Africa 1550 - 1990.
- South African Weather Service Publication. 2006. Caelum - A History of Notable Weather Events in South Africa 1991 - 2005.
- South African Weather Bureau, Regional Description of the Weather and Climate of South Africa: The Weather and Climate of the Extreme South-Western Cape, DEAT, 1996.
- Le Roux J J, Climate of South Africa. Part 11: Extreme Values of rainfall, temperature and Wind for Selected Return Periods, WB 36, Weather Bureau, Department of Transport, Pretoria, 31 pp., 1983.

8.6.2 Bantamsklip Site

The following meteorological reports have been made available by Eskom:

- Cadman RJ, Preece AR, (1987), Meteorological Monitoring along Cape S E Coast during August 1987, TRR/N87/026
- Preece AR, (1988), Meteorological Monitoring along Cape Southern Coast during December 1987, TRR/N88/024

- Preece AR, (1988), Meteorological Monitoring along Cape Southern Coast during January 1988, TRR/N88/025
- Preece AR, (1988), Meteorological Monitoring along Cape Southern Coast during February 1988, TRR/N88/031
- Preece AR, (1988), Meteorological Monitoring along Cape Southern Coast during March 1988, TRR/N88/032
- Preece AR, (1988), Meteorological Monitoring along Cape Southern Coast during April 1988, TRR/N88/037
- Preece AR, (1988), Meteorological Monitoring along Cape Southern Coast during August 1988, TRR/N89/006
- Preece AR, (1988), Meteorological Monitoring along Cape Southern Coast during September 1988, TRR/N89/007
- Preece AR, (1988), Meteorological Monitoring along Cape Southern Coast during October 1988, TRR/N89/008
- Preece AR, (1988), Meteorological Monitoring along Cape Southern Coast during November 1988, TRR/N89/009
- Preece AR, (1988), Meteorological Monitoring along Cape Southern Coast during December 1988, TRR/N89/010
- Preece AR, (1989), Meteorological Monitoring along Cape Southern Coast during January 1989, TRR/N89/013
- Preece AR, (1989), Meteorological Monitoring along Cape Southern Coast during April 1989, TRR/N89/028
- Preece AR, (1989), Meteorological Monitoring along Cape Southern Coast during May 1989, TRR/N89/029
- Preece AR, (1989), Meteorological Monitoring along Cape Southern Coast during June 1989, TRR/N89/033
- Preece AR, (1989), Meteorological Monitoring along Cape Southern Coast during July 1989, TRR/N89/035
- Preece AR, (1989), Meteorological Monitoring along Cape Southern Coast during August 1989, TRR/N89/039
- Preece AR, (1989), Meteorological Monitoring along Cape Southern Coast during September 1989, TRR/N89/040
- Tosen GR, Cadman RJ, Preece AR, (1987), Meteorological Monitoring along Cape Southern Coast during September, TRR/N87/030
- Tosen GR, Preece AR, (1987), Meteorological Monitoring along Cape Southern Coast during November 1987, TRR/N88/009
- Eskom. Koeberg Site Safety Report. Chapter 12: Meteorology. 2005.
- Eskom Generation NSIP 005171, Southern Cape Summary Report. Rev 1. 1994

8.6.3 Thyspunt Site

The following meteorological reports have been made available by Eskom:

- Cadman RJ, Preece AR, (1987), Meteorological Monitoring along Cape S E Coast during August 1987, TRR/N87/026
- Cadman RJ, Preece AR, (1987), Meteorological Monitoring along Cape S E Coast during September 1987, TRR/N87/027
- Preece AR, (1988), Meteorological Monitoring along Cape East Coast during June 1988, TRR/N88/036
- Preece AR, (1988), Meteorological Monitoring along Cape East Coast during July 1988, TRR/N88/035

- Preece AR, (1988), Meteorological Monitoring along Cape East Coast during August 1988, TRR/N88/040
- Preece AR, (1988), Meteorological Monitoring along Cape East Coast during the second quarter of 1989, TRR/N88/032
- Preece AR, (1988), Meteorological Monitoring along Cape East Coast during the Third quarter of 1989, TRR/N89/037
- Tosen GR, Cadman R, Preece A, (1987), Meteorological Monitoring along Cape E Coast during January 1987, TRR/N87/005
- Tosen GR, Cadman RJ, Preece A, (1987), Meteorological Monitoring along Cape East Coast during March 1987, TRR/N87/011
- Tosen GR, Cadman RJ, Preece AR, (1987), Meteorological Monitoring along Cape E Coast during April 1987, TRR/N87/016
- Tosen GR, Cadman RJ, Preece AR, (1987), Meteorological Monitoring along Cape East Coast during May 1987, TRR/N87/020
- Tosen GR, Cadman R, Preece AR, (1987), Meteorological Monitoring along Cape East Coast during June 1987, TRR/N87/022
- Eskom. Koeberg Site Safety Report. Chapter 12: Meteorology. 2005.
- Eskom Generation NSIP 005171, Southern Cape Summary Report. Rev 1. 1994