WHALERS WAY ORBITAL LAUNCH COMPLEX

Air Quality Impact Assessment

Prepared for:

Southern Launch
Level 8, 70 Pirie Street
ADELAIDE SA 5000

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BASIS OF REPORT

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DOCUMENT CONTROL

Reference	Date	Prepared	Checked	Authorised
640.30035-R01-v1.1	27 August 2020	Johan Meline	Judith Cox	Graeme Starke
640.30035-R01-v1.0	22 July 2020	Johan Meline	Judith Cox	Graeme Starke

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1 Introduction

Southern Launch is proposing to construct the Whalers Way Orbital Launch Complex on land located at the southern tip of the Eyre Peninsula approximately 25 km from Port Lincoln.

The land for the orbital launch facility has an area of about 2,640 hectares (ha) and the launch complex is proposed to the south of the site within a smaller allotment of approximately 1,200 ha. The launch complex is proposed to have the capacity for 36 launches per year and be developed in five stages:

- Stage 1: A permanent launch pad and permanent launch support infrastructure.
- Stage 2: A second permanent launch pad and permanent launch support infrastructure.
- Stage 3: A permanent range operations centre and permanent visitors centre.
- Stage 4: A permanent engine test stand and test support infrastructure.
- Stage 5: Non-conventional launch facilities (not part of the current application)

The two launch pads are referred to as Launch Site A and Launch Site B. The intention is to:

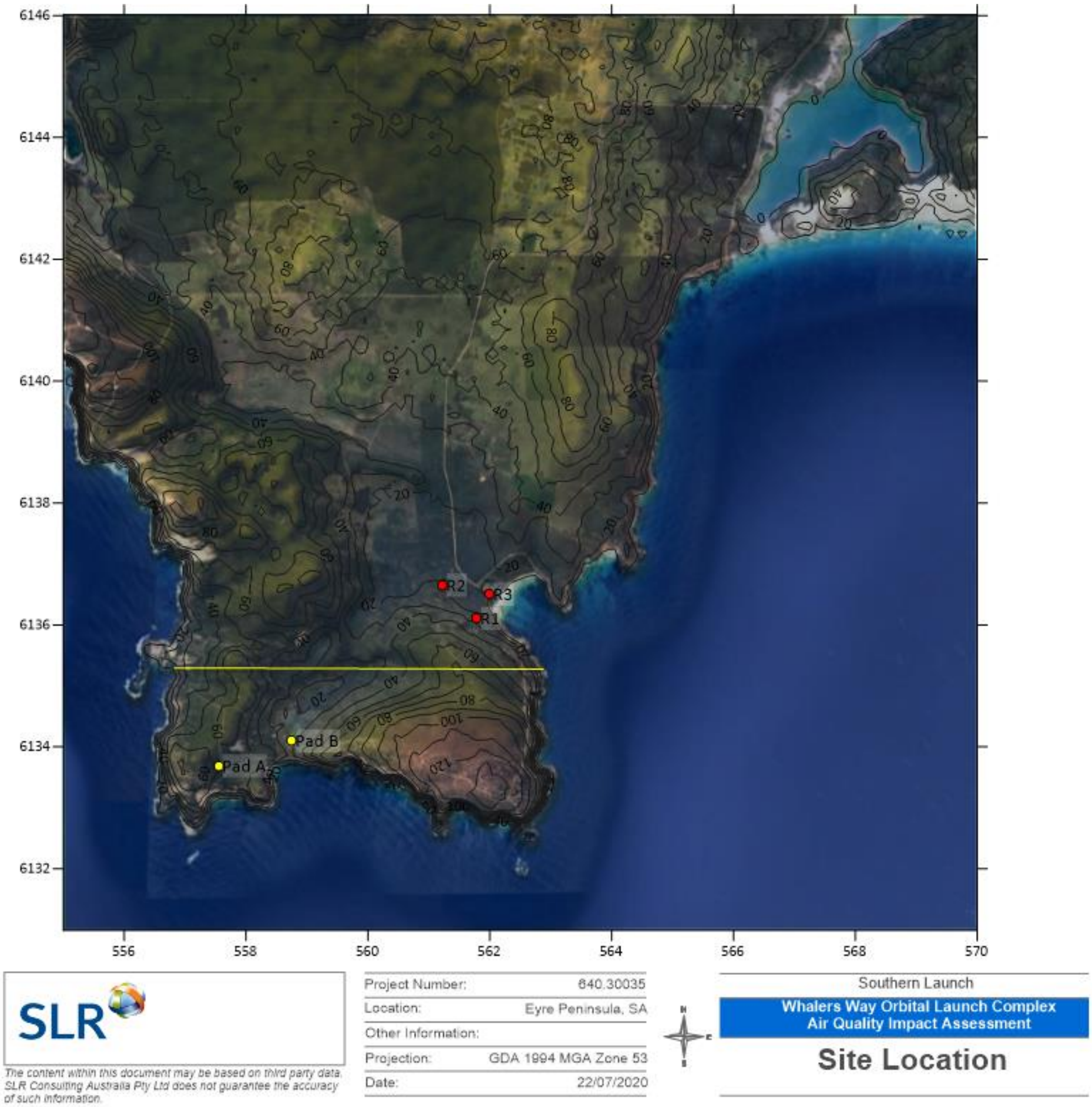
- Develop Launch Site B as Stage 1 for a range of launch vehicles sizes from micro to larger conventional (less than 10 tonnes to approximately 50 tonnes).
- Develop Launch Site A as Stage 2 for larger launch vehicles (greater than 30 tonnes to up to over 100 tonnes).

The location of the launch pads and nearest sensitive receptors are shown in **Figure 1**. The nearest sensitive receptors are located to the northwest at a distance of approximately 3.5 km from Launch Site B (Pad B) and 4.7 km from Launch Site A (Pad A).

For this air quality assessment emissions were estimated for dispersion modelling on a worst-case basis for the proposed operations considering the size of rockets and type of fuels. This included emissions from launches from Launch Site B (located closest to the nearest receptors) and rocket engine tests at the engine test facility located at Launch Site A for all times of day (24/7 operations).

Overall, the assessment considers worst-case impacts from the proposed operations which will include very short duration emission events on an infrequent basis. The emissions contributing to ground level concentrations are estimated to only last for up to 30 seconds for each launch. Discussion on the contribution to ground level concentrations from the vertical emissions profile from the launches is provided in the results. Details on the assessment methodology and how the rocket launches were modelled is provided in the assessment methodology section.

Figure 1 Site Location Showing Launch Site A, Launch Site B, Site Northern Land Boundary and Nearest Receptor Locations

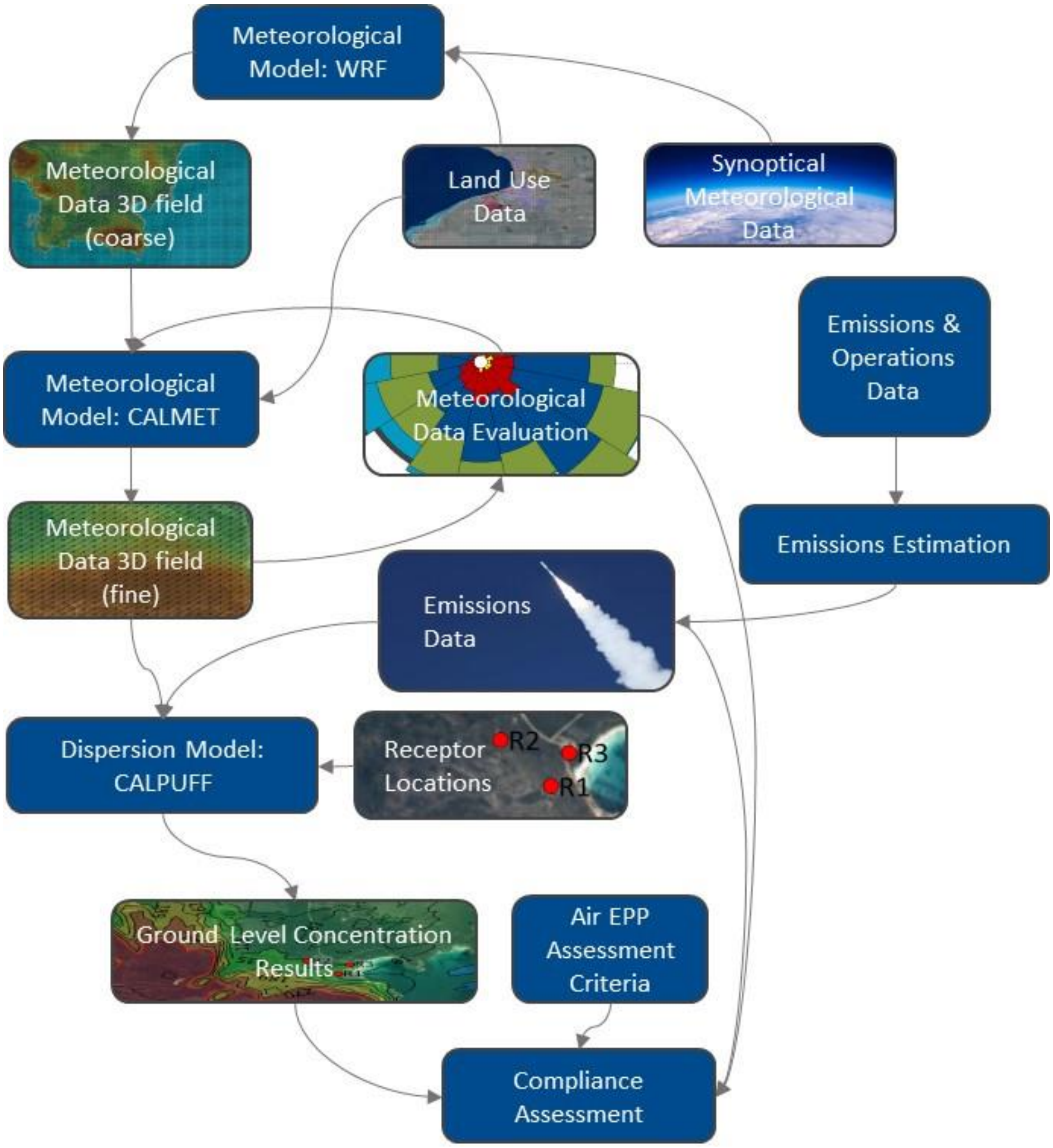


2 Assessment Methodology

2.1 Introduction

An overview of the air quality impact assessment dispersion modelling methodology is provided in **Figure 2**. Additional detail on each of the key aspects is detailed in the following sections.

Figure 2 Air Quality Assessment Dispersion Modelling Methodology Overview



2.2 Selection of Model Year, Meteorological Model and Dispersion Model

The year 2009 was selected for the dispersion modelling, being the standard year for assessment requested by the South Australian Environment Protection Authority (EPA).

Air quality assessment of rocket launches is not a typical application for dispersion modelling. In considering the elevation of the points of emission as the launch vehicles gains altitude, the meteorological model WRF was used for the best development of upper air data.

For the dispersion modelling CALPUFF was used. CALPUFF is the best choice model considering the project location and that sub-hourly emissions steps were required to characterise the short duration emission events for the assessment.

2.3 Processing of Meteorological Data

For the processing of the meteorological data required for the dispersion modelling (12 months of hourly timestep data) the weather research and forecasting model (WRF) was used to provide site representative data for the CALMET model for processing of the fine scale three-dimensional wind field data for the dispersion modelling.

- A description of the WRF model is available in the model description technical notes (NCAR, 2019).
- A description of the CALMET/CALPUFF model is available in the CALPUFF manual (SRC, 2011).

A summary of the meteorological model domain details is provided in **Table 1**.

Evaluation of the processed meteorological data is provided in **Appendix A** and shows typical near coastal windy conditions favourable for dispersion. Also, from an exposure point of view, the nearest sensitive receptors are not located downwind in any prevailing wind direction.

Table 1 WRF and CALMET Modelling Domain Details

Model and domain settings	Details
WRF	
4 nested grids	1,823 km x 1,829 km 153 km x 153 km 69 km x 69 km 26 km x 26 km Inner domain centre point: E: 559,619 N: 6,135,493
CALMET	
Domain size	15 km x 15 km
Receptor grid	100 m resolution
Domain origin	Southwest corner: E: 555,000 N: 6,131,000
Initial guess field	3D output from WRF
Further details on model settings can be provided as required.	

2.4 Dispersion Model

CALPUFF was used for the dispersion modelling. CALPUFF is widely used in Australia and is capable model for a range of applications and conditions such as larger scale modelling assessments and complex meteorological/terrain settings such as near coastal areas with land/sea interactions on dispersion.

A summary of the meteorological model domain details and model settings are provided in **Table 2**.

Table 2 CALPUFF Domain Details and Model Settings

Item	Details
Domain details	Same computational grid size and resolution as for CALMET.
Receptor details	In addition to the gridded domain receptors, three discrete receptors were included to account for assessment of ground level concentrations at the nearest sensitive receptor locations: **R1:** E: 561,779 N: 6,136,105 **R2:** E: 561,216 N: 6,136,652 **R3:** E: 561,988 N: 6,136,505
Modelling time step	Sub-hourly as 60 s.
Emissions data	Variable external emissions files.
Further details on model settings can be provided as required.	

2.5 Emissions Estimation

The air quality related emissions of significance for the proposed orbital launch complex are from the rocket launches and engine tests. It is understood that there may be up to 36 launches per year when the facility is fully developed and a smaller number of engine tests, mostly smaller in scale. Considering this, emissions were estimated for two emissions scenarios:

- Rocket launch
- Engine test

The duration of each emission event is very short considering the speed at which rockets accelerate and gain altitude. Typically, orbital launch vehicle rockets are launched with three stage burns (three stage motors).

For assessment of air quality in relation to implications for ground level concentrations it is only the portion of engine exhausts that are emitted below the mixing height that has the potential to be mixed to ground level.

As such, emissions were estimated for the portion of emissions from the Stage 1 burn up to an altitude of 3,000 m (which is the upper level of mixing height as typically set in CALPUFF). The duration to reach 3,000 m altitude for the launch vehicles that are being considered is approximately 30 seconds. Typically, the Stage 1 engine burn lasts for about 2.5 minutes.

With the shortest time step in CALPUFF being 60 seconds the duration of the emission events for the two scenarios were set to:

- Rocket launch – 1 minute
- Engine test – 3 minutes

From a literature review for references to emissions data for orbital launch facilities it appears that facilities are typically located in fairly remote areas without nearby receptors. Due to remoteness there is typically recognition that air quality impacts are unlikely to affect receptors. Given this, assessments are typically more qualitative than quantitative and the level of detail available on rocket engine exhaust launch emissions are limited. Also, in relation to emissions data for the emissions estimation for the assessment there will be a range of rockets launched at the facility and all details regarding all potential rockets and fuels are not available at this stage.

Considering the level of detail available for both rocket engine exhaust emissions in general, and the rockets that may be launched from the proposed orbital launch complex, the emissions estimation was focused on potential worst-case emissions of each pollutant.

The emission rates for each pollutant depend on the size of the rocket (engine capacity) and the rocket fuel type. In essence there are two types for rocket fuels: liquid fuels and solid fuels.

From a review of rocket engine exhaust emissions data. the following pollutants were identified as relevant to include in the assessment to cover both liquid and solid fuel emissions:

- Carbon monoxide (CO) – combustion product from liquid RP1 (kerosene) fuel.
- Nitrogen oxides as nitrogen dioxide (NO_2) – combustion product from liquid RP1 (kerosene) fuel.
- Hydrogen chloride (HCl) – emitted from certain solid fuel engines.
- Particulate matter (PM) as for combustion emissions assumed to be fine particulate matter ($PM_{2.5}$) – emitted as part of all combustion however worst-case emissions are from solid fuels.

Due to operational circumstances, a rocket could be launched at any time of day. As such, it was conservatively assumed that emissions would occur all times of day.

However, also considering that the emissions only occur for a very short duration, that there will be no consecutive launches within short time periods and that the emission rates are very high (compared to standard dispersion modelling applications), variable emissions files were set up including a rocket launch/engine test every second hour of the year for each scenario. As such the modelling includes assessment of a total of 4,380 launch events and 4,380 engine tests. The annual total of proposed launches is 36 and the number of engine tests will be very few and mostly much smaller scale than assumed.

By allowing for the emission events of one and three minutes in duration occurring every second hour, it is expected that there will be no cumulative impacts to ground level concentration from consecutive launches (which will not occur)[1] while still allowing for assessment of all time of day conditions.

Details on the emissions calculations are provided in **Section 3**.

[1] The distance to the nearest receptors for Launch Site B is approximately 3,500 m. Travel distance of ambient air at 0.5 m/s with a persistent wind direction over 2 hours is 3.6 km.

Other emissions from site that have been identified are from smaller generators for powering of the facility buildings and operations. Onsite power generation may be a temporary arrangement until grid power is connected at a later stage in the site development. Alternatively, it is also understood that a solar panel/battery option is being considered for the site. The generator emissions are not large scale and not significant for assessment.

There will also be some dust emissions from site for the site construction activities. This is however expected to be managed as for conventional civil construction requirements and the scale of the activities will not have a nuisance impact on the nearest receptors considering the distances to receptors from the facility site areas.

2.6 Evaluation of Ground Level Concentrations and Assessment Criteria

For the evaluation of air quality impacts, and the assessment of compliance for the proposed operations, the predicted maximum ground level concentrations were assessed against the South Australian Air Quality Environment Protection Policy (Air EPP) ground level concentration assessment criteria as presented in **Table 3**.

As discussed above, while the emission rates from the activities are high, the duration of each emission event is less than a minute for a launch, and only up to a few minutes for an engine test. With a total of 36 launches planned per year, the duration between launches is expected to be in the range of several days to a couple of weeks. Considering this, assessment is most relevant against the short term 1 hour and 3 minute averaging period assessment criteria as listed in the Air EPP.

For the evaluation against the $PM_{2.5}$ 24 hour criterion the maximum hourly concentration as contribution to a 24 hour average was considered.

For this assessment which considers very short term duration emission events, background concentrations have not been included specifically in the results evaluation. Focus of the results presentation was on demonstrating the predicted resulting maximum incremental ground level concentrations. Given the location of the launch complex there is not expected to be any background concentrations of significance for CO, NO_2 or HCl. For context to the $PM_{2.5}$ predicted concentrations the $PM_{2.5}$ background concentration was considered in the results discussion.

Table 3 Air EPP Maximum Ground Level Concentration Assessment Criteria (SA, 2016)

Pollutant	Classification	Averaging time	Maximum ground level concentration	Comment
CO	Toxicity	1 hour	31,240 µg/m³	
		8 hours	11,250 µg/m³	Not relevant to include considering short term duration of emission events.
NO_2	Toxicity	1 hour	250 µg/m³	
		12 months	60 µg/m³	Not relevant to include considering short term duration of emission events.
HCl	Toxicity	3 minutes	270 µg/m³	
$PM_{2.5}$	Toxicity	24 hours	25 µg/m³	Contribution to 24 hour average calculated from maximum predicted ground level concentration.
		12 months	8 µg/m³	Not relevant to include considering short term duration of emission events.

3 Emissions Data

As discussed in **Section 2.5,** emissions were estimated for scenarios covering worst-case emissions from launch and engine test events. A summary of the emissions calculations and source characteristics are provided below.

Full details on the rocket information and data cannot be provided due commercial agreements between Southern Launch and the clients they have early agreements with.

As discussed previously, the emissions data available for the proposed rocket types, and also for air quality assessments of rocket launch facilities in general, is very limited. As such emission rates were estimated based on available emissions data and scaled based on exhaust and fuel consumption rates. Also as discussed in the emissions estimation section, emissions up to 3,000 m were included.

The emissions estimation was based on a conservative selection of emissions data. A summary on relevant data and references are provided in **Table 4** and **Table 5**.

The worst-case emissions estimation for the engine test was based on a full Stage 1 burn of the liquid fuel 58 t rocket engine, since large scale solid fuel engines are never tested at locations other than the development facility.

Table 4 Emission Rate Calculations Based on Liquid Fuel

Scenario	Pollutant	Launch vehicle mass (including fuel) (t)	Fuel consumption rate (kg/s)	Pollutant exhaust mass fraction/ mass	Time to 3,000 m (s)	Emission rate (kg/s)	Emissions to reach 3,000 m (kg)	Time for Stage 1 burn (s)	Emissions for Stage 1 burn (kg)
Launch Engine test	CO	58 [a]	420 [a]	24.76% [b]	27	104.0	2816.5	100	10,399.2
Launch Engine test	NO_x as 100% NO_2			2.313 lb/s		2.2 [d]	60.5		223.5
Engine test	PM			0.5 % [b]		2.1	NA		210.0

[a] Source: Southern Launch
[b] Source: (Federal Aviation Administration, 2020) Table 4.1 at engine exit before after burn in exhaust plume[2]
[c] Source: (Federal Aviation Administration, 2020) Table 4.1
[d] Calculated as scaled on engine exhaust/fuel consumption rates and converted to 100% NO_2 from 100% NO

Table 5 Emission Rate Calculations Based on Solid Fuel

Scenario	Pollutant	Launch vehicle mass (including fuel) (t)	Fuel consumption rate (kg/s)	Pollutant exhaust mass fraction	Time to 3,000 m (s)	Emission rate (kg/s)	Emissions to reach 3,000 m (kg)
Launch	HCL	41 [a]	338 [a]	21.4% [b]	24	72.3	1,705.2
Launch	PM			28.4% [b]		95.9	2,263.0

[a] Source: Southern Launch
[b] Source: (D. Schuch, 2017) Table 1

Emission rates were calculated for the duration of travel to 3,000 m, and were then divided between the levels for the dispersion model sources as presented in **Table 6** (launch scenario) and **Table 7** (engine test scenario).

One volume source was included for each layer of the meteorological cell data layers. By characterising the emissions sources as a volume sources it was conservatively assumed that the exhaust plume was of ambient temperature and that there was no buoyancy for the exhaust plumes.

Emissions were set in one variable emissions file for each scenario to occur for one minute every second hour for the launch scenario and for three minutes every second hour for the engine test scenario.

[2] Emissions for both CO and PM are listed zero in the mixed exhaust (after afterburn).

Table 6 Emissions Data for Launch Scenario

CALMET layers	Elevation of source (m)	Sigma y (m)	Sigma z (m)	CO emission rate (g/s)	NO_2 emission rate (g/s)	HCl emission rate (g/s)	PM emission rate (g/s)
2000 to 3000 m	2,500 m	5	250	15,647	336	9,473	12,572
1200 to 2000 m	1,600 m	5	200	12,518	269	7,579	10,058
640 to 1200 m	920 m	5	140	8,763	188	5,305	7,040
320 to 640 m	480 m	5	80	5,007	108	3,031	4,023
160 to 320 m	240 m	5	40	2,504	54	1,516	2,012
80 to 160 m	120 m	5	20	1,252	27	758	1,006
40 to 80 m	60 m	5	10	626	13	379	503
20 to 40 m	30 m	5	5	313	7	189	251
0 to 20 m	10 m	5	5	313	7	189	251
Total emissions (g/s)				46,942	1,009	28,420	37,716
Total emissions over 60 s (kg)				2,816.5	60.5	1,750.2	2,263.0
Source location	Pad B: E: 558.744, N: 6134.099						

Table 7 Emissions Data for Engine Test Scenario

	Elevation of source (m)	Sigma y (m)	Sigma z (m)	CO emission rate (g/s)	NO_2 emission rate (g/s)	PM emission rate (g/s)
Engine test emission rates	10	15	5	57,773	1,242	1,167
Total emissions over 180 s (kg)				10,399.2	223.5	210.0
Source location	Pad A: E: 557.542, N: 6133.686					

4 Results

4.1 Introduction

The results for the two assessment scenarios are presented below and include:

- Contour plots for predicted maximum ground level concentrations for launches in **Figure 3** to **Figure 6** and are discussed in **Section 4.2**.
- Contour plots for predicted maximum ground level concentrations for engine tests in **Figure 7** to **Figure 9** and are discussed in **Section 4.3**.
- Maximum ground level concentrations and top ten predicted ground level concentrations for launches and engine tests in **Table 8** and **Table 10**.
- An analysis of elevated source contribution to ground level concentrations is provided in **Table 9**.

All contour plots show the incremental ground level concentrations due to the operations (excluding background concentrations).

The contour plots are included with a colour shading based on the percentage of the assessment criteria to simplify the review of the results plots and to make it easier to compare between scenarios and pollutants. The fields are provided in 10% segments, also including segments for 5% and 1% levels of the Air EPP as a minimum of the assessment criteria. The Air EPP assessment criteria are shown as red contours.

4.2 Launch Scenario

The results for the launch scenario show the following:

- The CO result show low levels of maximum predicted ground level concentrations at the nearest receptors (less than 1% of the Air EPP assessment criterion).
- The NO_2 emissions were conservatively estimated assuming 100% conversion of NO_x to NO_2 and show low levels of maximum predicted ground level concentrations at the nearest receptors (approximately 1% of the Air EPP assessment criterion).
- The HCl results show predicted maximum ground level concentrations in the order of approximately 40% of the Air EPP assessment criterion at the nearest receptors.
- PM results, as assessed against the $PM_{2.5}$ assessment criterion show a maximum 1 hour average ground level concentration of 84.1 µg/m^3 which translates to a 24 hour average contribution of 3.5 µg/m^3. This is approximately 14 % of the 25 µg/m^3 Air EPP criterion. If including a background concentration of a similar value to the 70th percentile for $PM_{2.5}$ as measured in Port Augusta of around 7 µg/m^3 there is still significant margin before an exceedance of Air EPP criterion.
- The results in **Table 9** show that there is no contribution to the top thirty ground level concentrations from the sources in the modelling above 1,200 m. The highest ground level concentrations are predicted in stable conditions with low wind speeds and low mixing heights. On the occasions with contribution from higher elevation sources this is typically in conditions with higher mixing heights and more unstable conditions achieving vertical mixing. Overall. it is the stable low wind speed and low mixing height conditions that contribute to the highest ground level concentrations. **Table 9** is presented with conditional formatting colour coding for overview visualisation of the data contribution.

This shows that while the emission rates for the rocket launches are very high the emission events only occur for a very short durations and that is only the portion of the lower levels of emissions during launch (up to around 1,200 m) that contribute to ground level concentrations. Emissions above 1,200 m which make up the greater part of the launch emissions are not mixed to ground level and are dispersed in upper air layers.

Figure 3 Results for CO for Launch Scenario

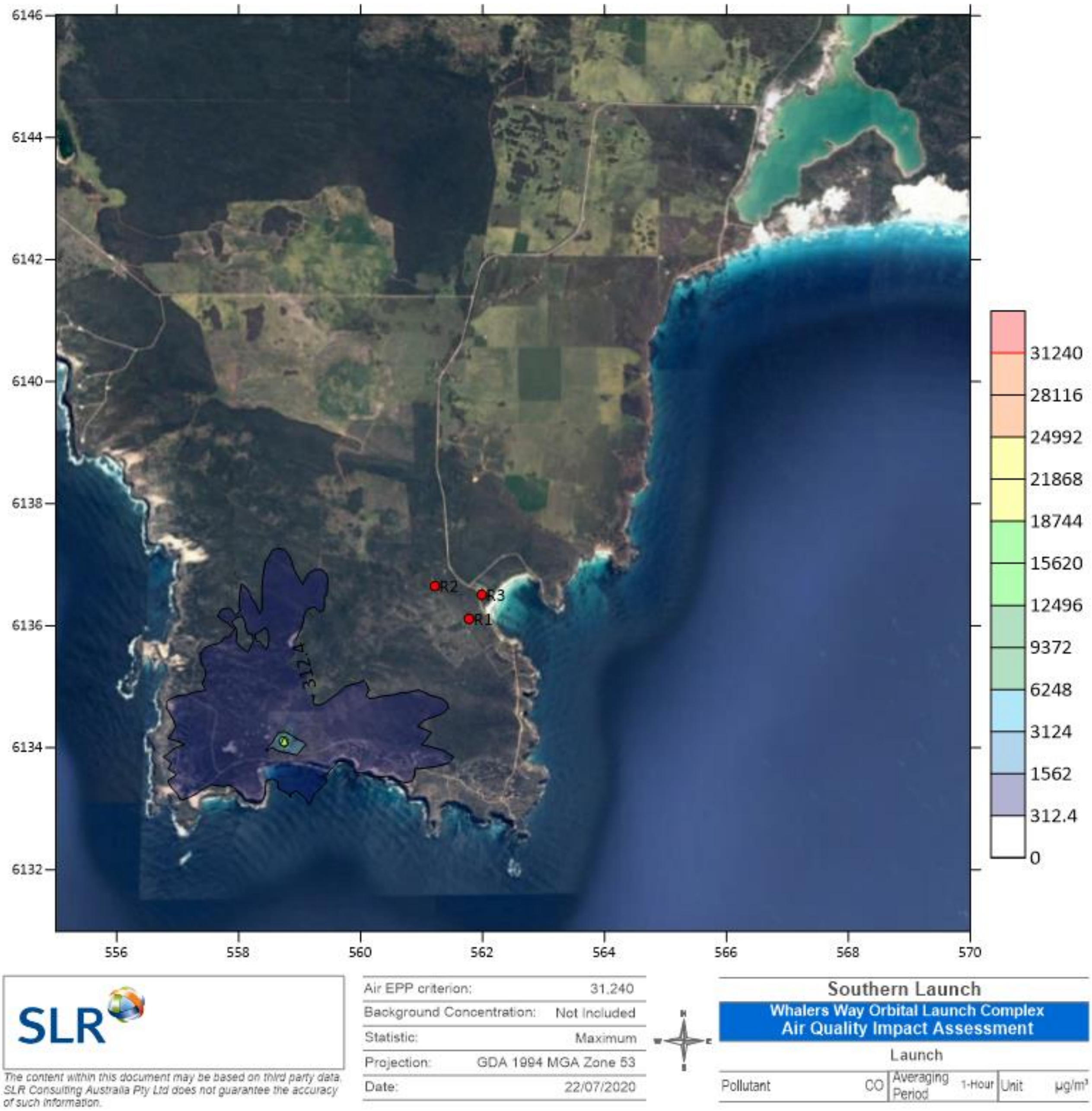
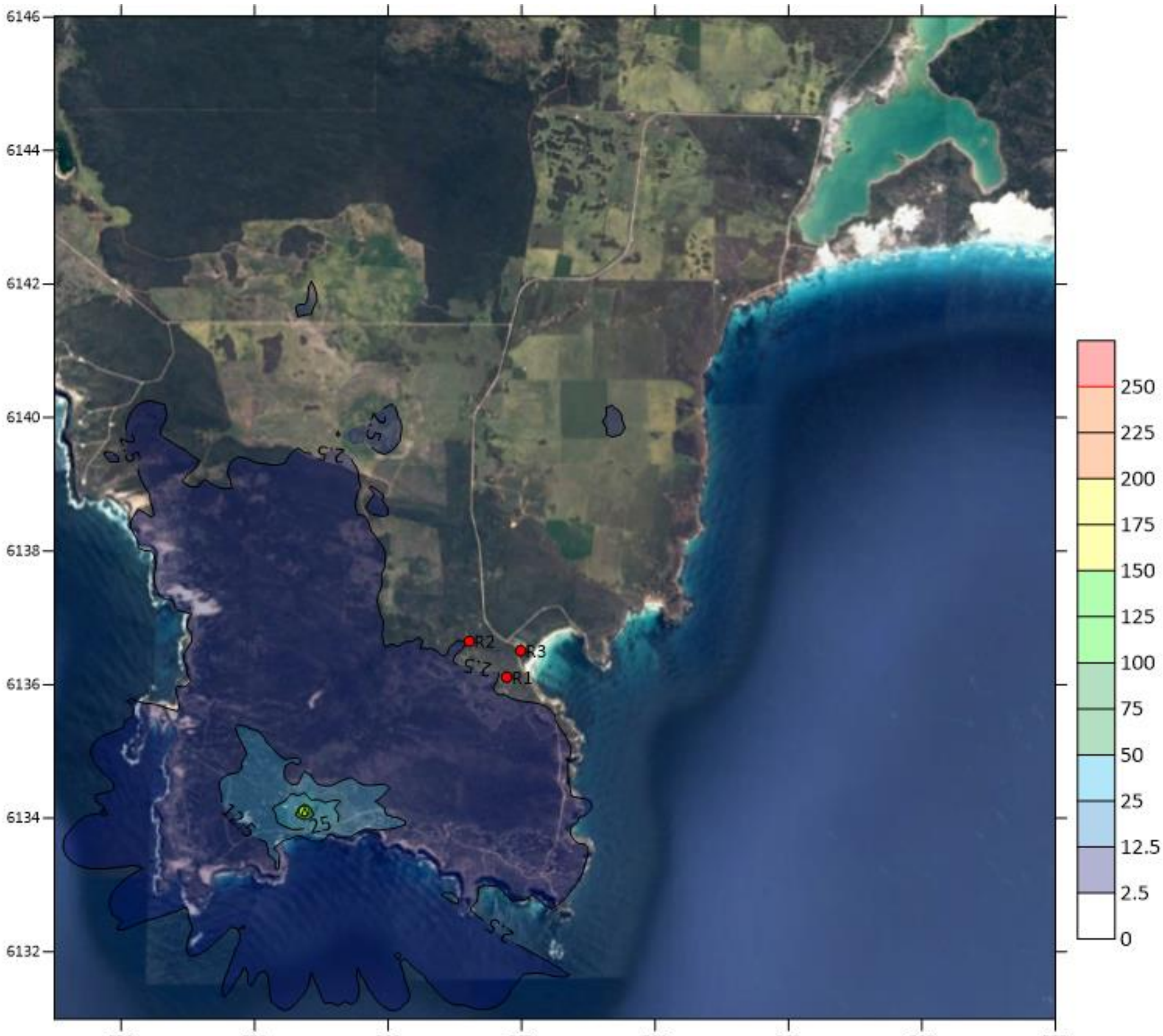


Figure 4 Results for NO_2 for Launch Scenario



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Air EPP criterion:	250
Background Concentration:	Not Included
Statistic:	Maximum
Projection:	GDA 1994 MGA Zone 53
Date:	22/07/2020

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Pollutant	NO_x (100% conv)	Averaging Period	1-Hour	Unit	µg/m³

Figure 5 Results for HCl for Launch Scenario

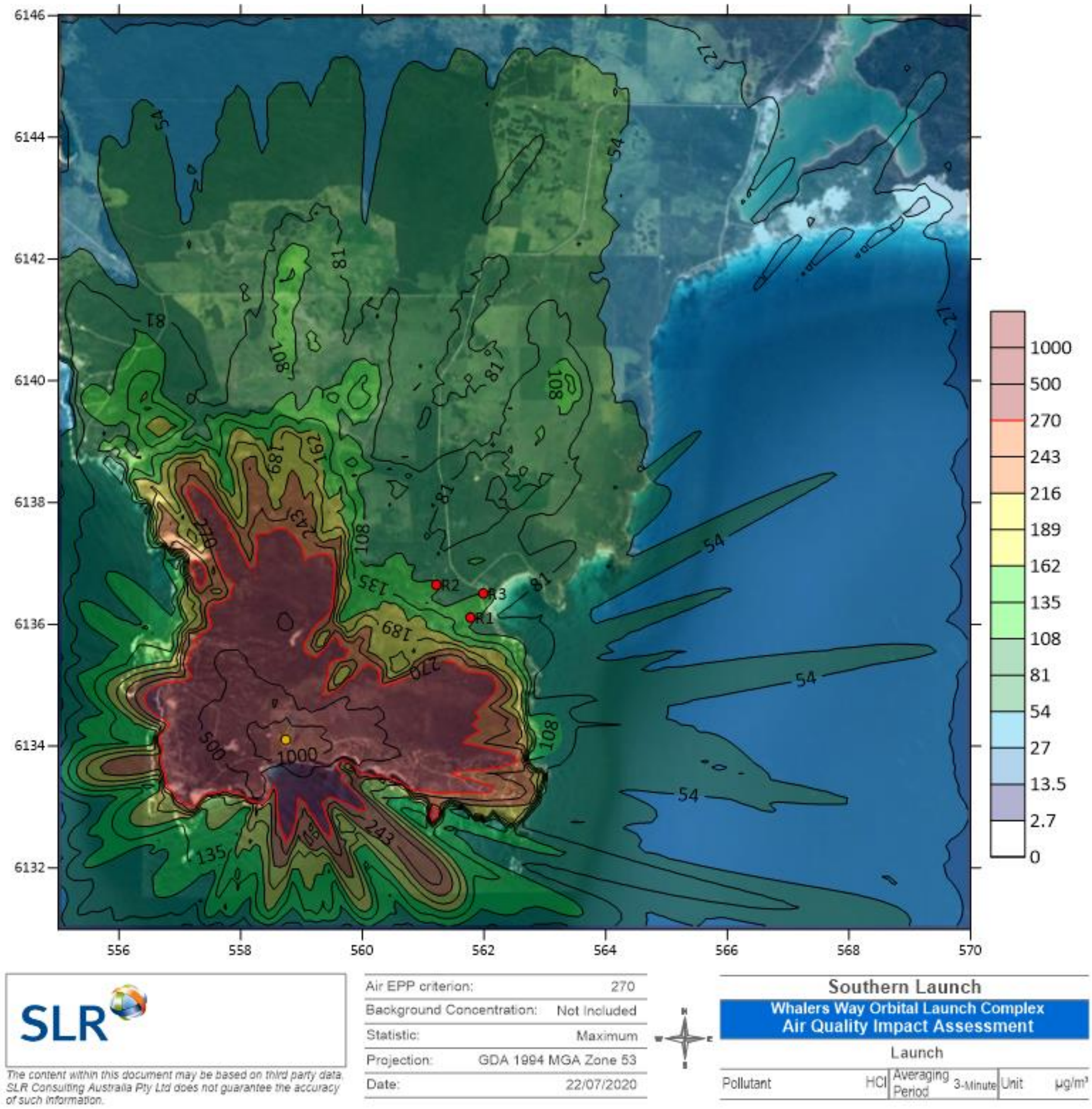

Figure 6 Results for $PM_{2.5}$ for Launch Scenario

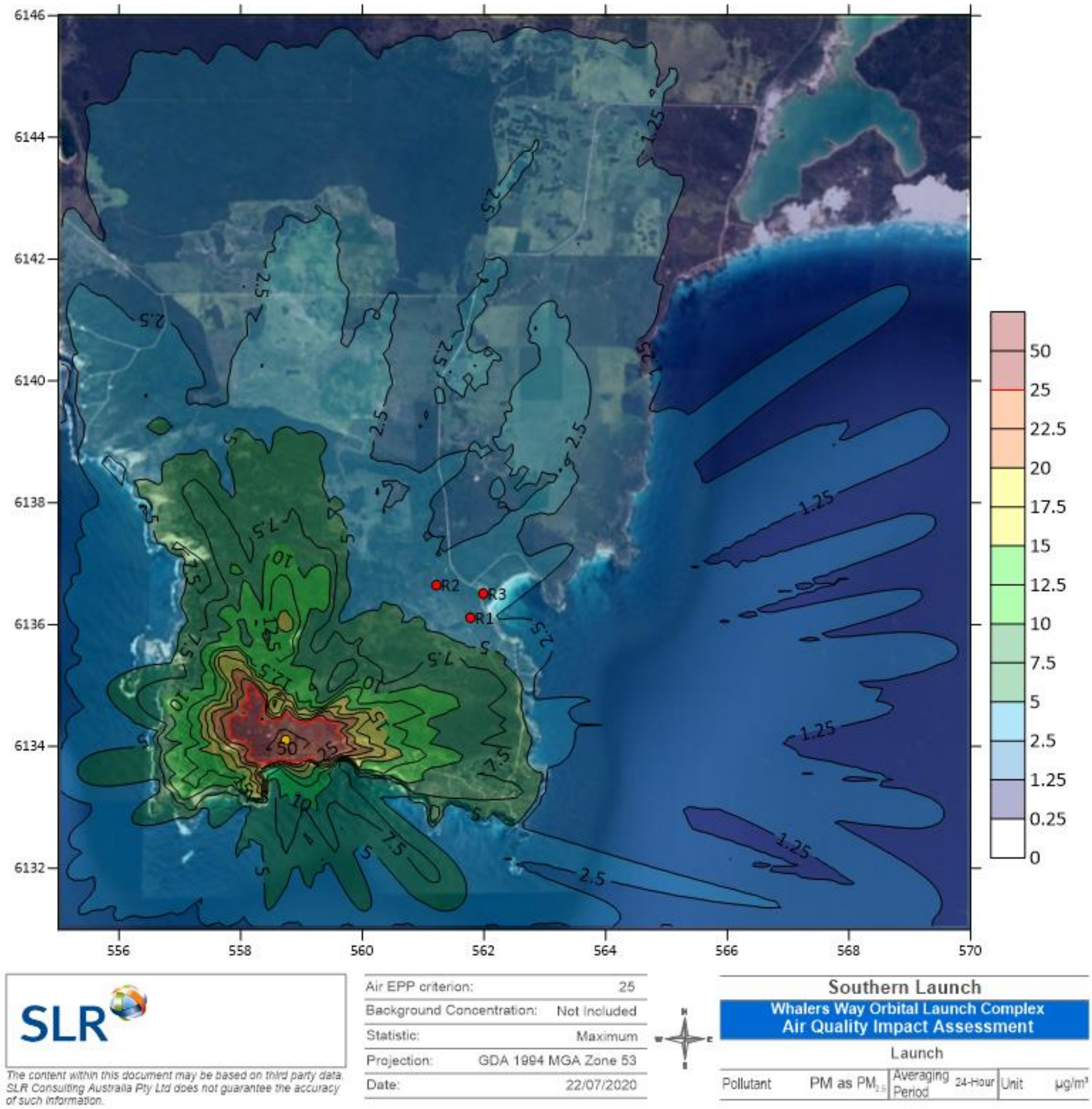

Table 8 Top 10 Ground Level Concentrations for R2 and Meteorological Conditions for Launch Scenario

Rank	Date stamp	Maximum GLC 1 hr avg except for HCl 3 min avg (µg/m³)	Wind speed (m/s)	Wind direction (°)	Stability class	Mixing height (m)
CO	Air EPP Assessment Criteria: 31,240 (µg/m³)					
Maximum	2009/05/02 17:00	104.9	1.8	218	F	61
2nd highest	2009/07/23 03:00	96.0	1.6	194	F	70
3rd highest	2009/05/26 07:00	93.6	2.6	219	D	72
4th highest	2009/12/11 19:00	88.5	3.3	224	F	118
5nd highest	2009/11/27 05:00	87.7	1.7	213	C	130
6rd highest	2009/12/12 01:00	86.6	3.1	224	F	110
7th highest	2009/12/19 03:00	86.2	4.0	222	E	164
8nd highest	2009/03/16 05:00	84.0	4.3	223	E	203
9rd highest	2009/05/02 15:00	84.0	2.3	228	C	530
10th highest	2009/11/23 19:00	82.0	2.7	226	F	70
HCl	Air EPP Assessment Criteria: 270 (µg/m³)					
Maximum	2009/05/02 17:00	115.2	1.8	218	F	61
2nd highest	2009/07/23 03:00	105.5	1.6	194	F	70
3rd highest	2009/05/26 07:00	102.8	2.6	219	D	72
4th highest	2009/12/11 19:00	97.2	3.3	224	F	118
5nd highest	2009/11/27 05:00	96.5	1.7	213	C	130
6rd highest	2009/12/12 01:00	95.2	3.1	224	F	110
7th highest	2009/12/19 03:00	94.8	4.0	222	E	164
8nd highest	2009/05/02 15:00	92.5	2.3	228	C	530
9rd highest	2009/03/16 05:00	92.4	4.3	223	E	203
10th highest	2009/11/23 19:00	90.1	2.7	226	F	70
NO_2 (as 100% of NOx) Air EPP Assessment Criteria: 250 (µg/m³)						
Maximum	2009/05/02 17:00	2.3	1.8	218	F	61
2nd highest	2009/07/23 03:00	2.1	1.6	194	F	70
3rd highest	2009/05/26 07:00	2.1	2.6	219	D	72
4th highest	2009/12/11 19:00	2.0	3.3	224	F	118
5nd highest	2009/12/12 01:00	1.9	3.1	224	F	110
6rd highest	2009/12/19 03:00	1.9	4.0	222	E	164
7th highest	2009/11/27 05:00	1.9	1.7	213	C	130
8nd highest	2009/03/16 05:00	1.8	4.3	223	E	203
9rd highest	2009/11/23 19:00	1.8	2.7	226	F	70
10th highest	2009/05/02 15:00	1.8	2.3	228	C	530
$PM_{2.5}$						

Rank	Date stamp	Maximum GLC 1 hr avg except for HCl 3 min avg (µg/m³)	Wind speed (m/s)	Wind direction (°)	Stability class	Mixing height (m)
Maximum	2009/05/02 17:00	84.1	1.8	218	F	61
2nd highest	2009/07/23 03:00	77.0	1.6	194	F	70
3rd highest	2009/05/26 07:00	75.0	2.6	219	D	72
4th highest	2009/12/11 19:00	71.0	3.3	224	F	118
5nd highest	2009/11/27 05:00	70.4	1.7	213	C	130
6rd highest	2009/12/12 01:00	69.5	3.1	224	F	110
7th highest	2009/12/19 03:00	69.2	4.0	222	E	164
8nd highest	2009/05/02 15:00	67.5	2.3	228	C	530
9rd highest	2009/03/16 05:00	67.4	4.3	223	E	203
10th highest	2009/11/23 19:00	65.7	2.7	226	F	70

Table 9 Top 30 Ground Level Concentrations and Percentage Contributions from Elevated Sources for R2 and Meteorological Conditions for Launch Scenario

Date and Time Stamp	Max GLC CO (µg/m³)	% Contribution to Ground Level Concentration (GLC) From Each Layer									Wsp (m/s)	Stab Class	MxHt (m)
		0 to 20 m	20 to 40 m	40 to 80 m	80 to 160 m	160 to 320 m	320 to 640 m	640 to 1,200 m	1,200 to 2,000 m	2,000 to 3,000 m			
2009/05/02 17:00	104.9	95.8%	4.2%	0.0%	0.0%	0.0%	0.0%	0.0%	0%	0%	1.8	F	61
2009/07/23 03:00	96.0	46.8%	40.5%	12.6%	0.0%	0%	0%	0%	0%	0%	1.6	F	70
2009/05/26 07:00	93.6	79.1%	20.9%	0.0%	0%	0%	0%	0%	0%	0%	2.6	D	72
2009/12/11 19:00	88.5	57.8%	41.1%	1.0%	0.0%	0.0%	0.0%	0.0%	0%	0%	3.3	F	118
2009/11/27 05:00	87.7	21.1%	21.2%	53.8%	3.9%	0.0%	0.0%	0.0%	0%	0%	1.7	C	130
2009/12/12 01:00	86.6	63.3%	36.6%	0.0%	0.0%	0.0%	0.0%	0.0%	0%	0%	3.1	F	110
2009/12/19 03:00	86.2	47.0%	36.6%	16.4%	0.0%	0.0%	0.0%	0.0%	0%	0%	4.0	E	164
2009/03/16 05:00	84.0	42.2%	36.3%	21.6%	0.0%	0.0%	0.0%	0.0%	0%	0%	4.3	E	203
2009/05/02 15:00	84.0	7.2%	6.0%	10.2%	19.1%	31.0%	26.5%	0.0%	0%	0%	2.3	C	530
2009/11/23 19:00	82.0	86.4%	13.6%	0.0%	0.0%	0.0%	0.0%	0.0%	0%	0%	2.7	F	70
2009/03/15 05:00	80.1	39.0%	35.6%	25.4%	0.0%	0.0%	0.0%	0%	0%	0%	4.5	E	216
2009/05/26 05:00	77.8	72.0%	28.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0%	0%	3.0	F	95
2009/11/23 17:00	77.6	9.3%	8.1%	13.1%	22.9%	31.3%	15.4%	0%	0%	0%	2.5	D	520
2009/05/02 19:00	74.2	73.5%	26.4%	0.1%	0.0%	0.0%	0.0%	0.0%	0%	0%	1.6	F	57
2009/04/05 05:00	72.7	34.5%	36.0%	29.0%	0.6%	0.0%	0.0%	0%	0%	0%	5.3	E	280
2009/04/17 19:00	68.7	97.3%	2.7%	0.0%	0.0%	0.0%	0%	0%	0%	0%	1.7	F	57
2009/05/03 15:00	66.6	6.0%	4.8%	9.0%	17.7%	29.2%	33.2%	0%	0%	0%	2.4	C	541
2009/09/16 19:00	66.5	31.9%	32.3%	34.3%	1.5%	0.0%	0.0%	0%	0%	0%	5.6	D	313
2009/04/29 15:00	63.7	7.8%	6.8%	12.7%	23.9%	32.6%	16.2%	0%	0%	0%	4.0	C	574
2009/03/06 07:00	62.4	9.0%	7.6%	13.5%	27.0%	35.0%	7.9%	0%	0%	0%	2.8	C	573
2009/04/03 05:00	60.7	27.3%	25.7%	42.6%	4.3%	0.0%	0.0%	0%	0%	0%	6.2	D	354
2009/12/18 03:00	59.6	48.0%	50.5%	1.5%	0.0%	0.0%	0.0%	0%	0%	0%	3.4	E	122
2009/12/04 23:00	58.8	47.8%	32.4%	19.8%	0.0%	0.0%	0.0%	0%	0%	0%	3.9	E	167
2009/09/07 05:00	58.7	90.6%	9.4%	0.0%	0.0%	0.0%	0.0%	0%	0%	0%	2.4	F	68
2009/08/10 03:00	58.5	27.8%	23.6%	46.7%	1.9%	0.0%	0.0%	0%	0%	0%	5.7	D	302
2009/12/11 23:00	58.4	50.4%	49.3%	0.3%	0.0%	0.0%	0.0%	0%	0%	0%	3.1	F	110
2009/05/13 03:00	57.3	38.1%	43.5%	18.2%	0.2%	0.0%	0.0%	0%	0%	0%	5.0	E	252
2009/03/14 01:00	55.4	26.9%	27.0%	39.2%	7.0%	0.0%	0%	0%	0%	0%	6.7	D	394
2009/05/16 11:00	54.4	8.7%	8.1%	15.2%	28.1%	33.0%	6.9%	0%	0%	0%	4.8	D	488
2009/03/24 17:00	53.1	76.0%	24.0%	0%	0%	0%	0%	0%	0%	0%	1.4	C	53

4.3 Engine Test Scenario

The results for the engine test scenario show the following:

- The results for CO for the engine test scenario with a full Stage 1 burn and much higher emissions at ground level than for the launch scenario shows, as expected, much increased ground level concentrations of CO. The predicted concentrations are however still within compliance at the nearest receptors.
- Similarly to the CO results for the engine test the NO_2 ground level concentrations are also much increased compared to the launch scenario. However, instead of assuming 100% conversion of NO_x to NO_2 (as common for screening assessments) a conversion of 40% was applied for this scenario. The 40% conversion was referenced to (Jansen et al, 1988) for a distance of approximately 5 km in summer conditions. The predicted concentrations are still within compliance at the nearest receptors.
- For PM the contribution to 24 hour average shows a similar margin to the $PM_{2.5}$ Air EPP assessment criterion as CO and NO_2 for the engine test. If including a 70th percentile background concentration similar to what has been recorded in Port Augusta in recent years of around 7 µg/m^3 **Table 10** shows that only the maximum predicted hourly concentration would contribute to an exceedance.

The results for the engine test assuming a full Stage 1 burn at ground level for a 58 t rocket with liquid fuel within compliance for CO and NO_2 and marginally over for one day for PM as assessed against Air EPP $PM_{2.5}$ criteria. Considering the number of the very small number of engine tests that are being planned and that mostly smaller or shorter duration engine tests are anticipated the results show that engine tests are expected to be performed without exceedances of the Air EPP assessment criteria at the nearest sensitive receptors.

Figure 7 Results for CO for Engine Test Scenario

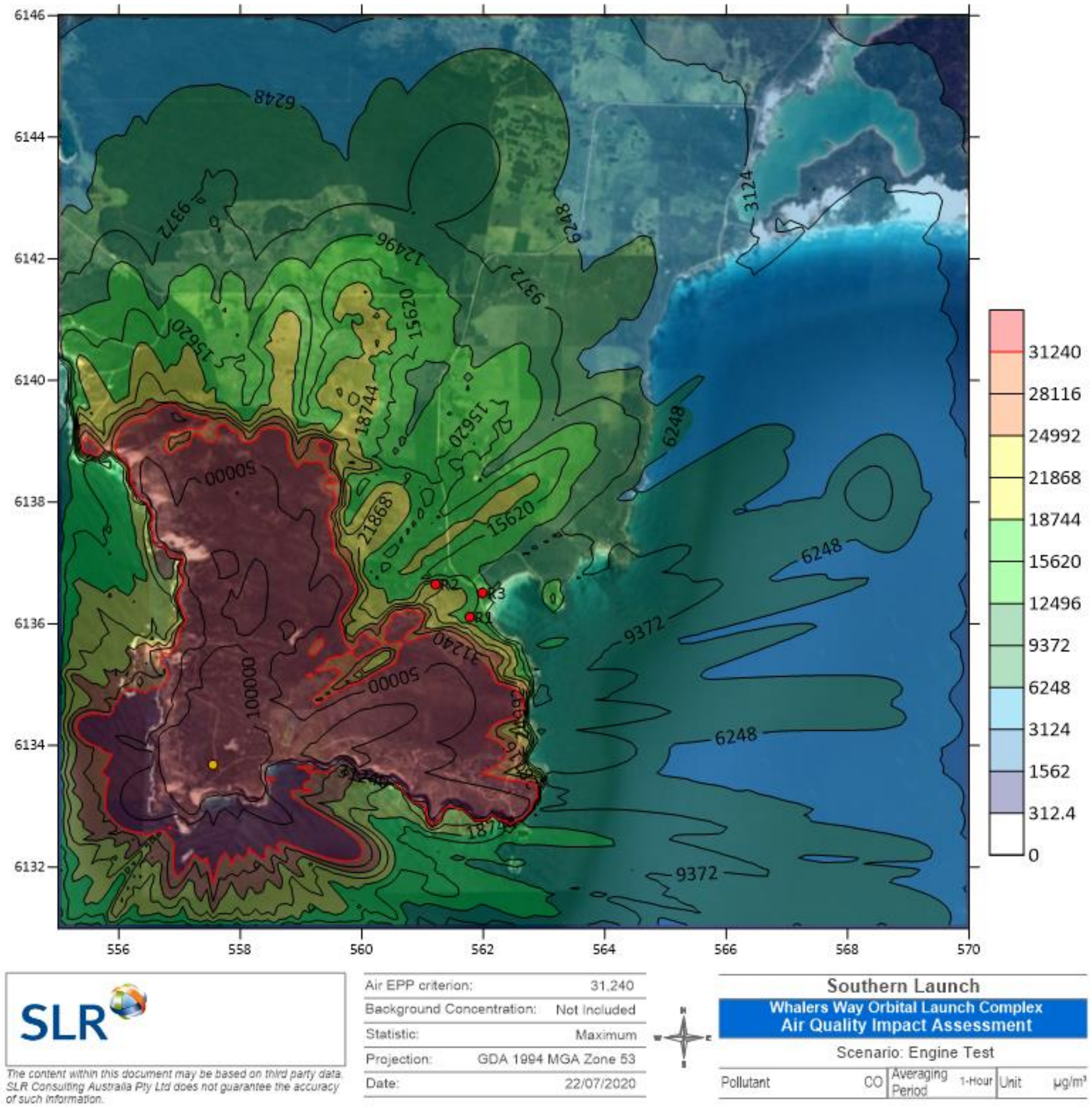

Figure 8 Results for NO_2 for Engine Test Scenario

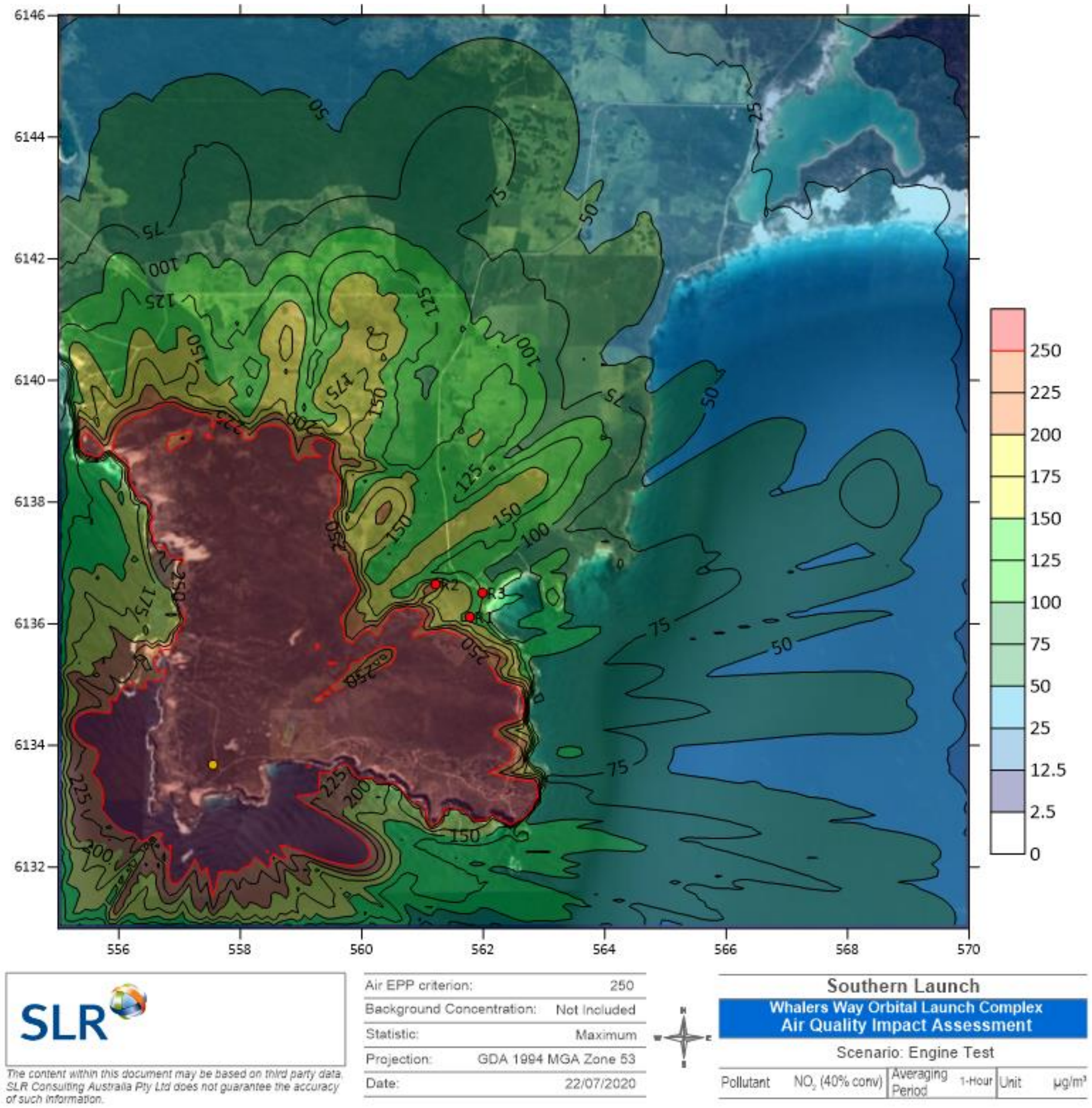

Figure 9 Results for $PM_{2.5}$ for Engine Test Scenario

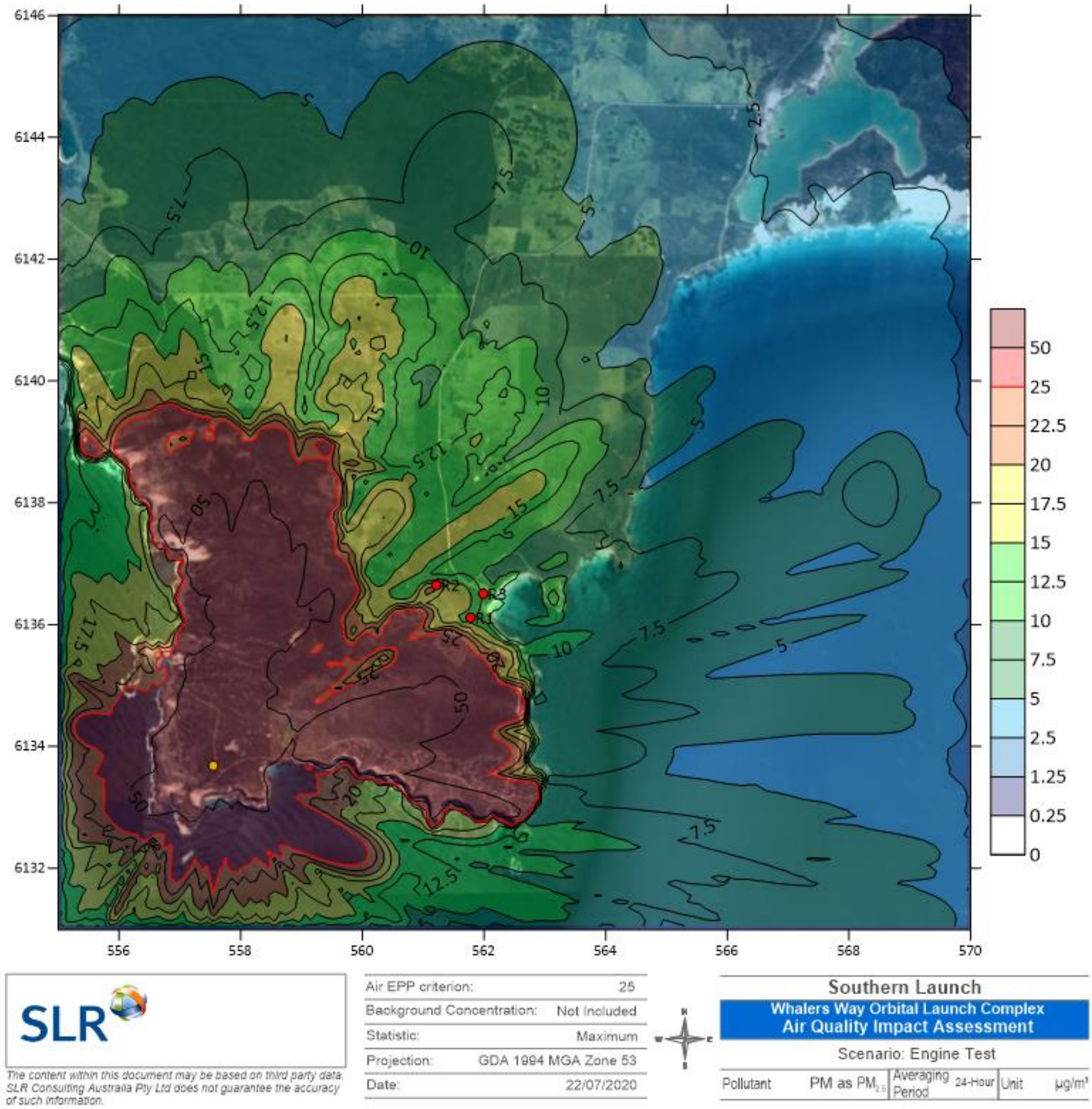

Table 10 Top 10 Ground Level Concentrations for R2 and Meteorological Conditions for Engine Test Scenario

Rank	Date stamp	Max GLC CO 1 hr avg (µg/m³)	Max GLC NO_2 (40%) 1 hr avg (µg/m³)	Max GLC $PM_{2.5}$ 1 hr avg (µg/m³)	$PM_{2.5}$ contrib. to 24 hr avg (µg/m³)	Wsp (m/s)	Wdir (°)	Stab class	MxHt (m)
Air EPP Assessment Criteria:		31,240	250	NA	25				
Maximum	2009/04/17 19:00	22,777	196	460	**19.2**	1.7	228	F	57
2nd highest	2009/12/11 21:00	17,713	152	358	14.9	2.8	229	F	78
3rd highest	2009/12/08 19:00	16,347	141	330	13.8	3.1	229	F	100
4th highest	2009/06/06 21:00	15,866	136	320	13.3	1.9	236	E	82
5nd highest	2009/04/14 05:00	14,439	124	292	12.2	3.0	227	F	97
6rd highest	2009/11/23 19:00	14,376	124	290	12.1	2.7	226	F	70
7th highest	2009/11/19 23:00	13,324	115	269	11.2	2.2	209	F	70
8nd highest	2009/12/11 23:00	13,116	113	265	11.0	3.1	227	F	110
9rd highest	2009/01/22 21:00	12,888	111	260	10.8	3.5	230	E	133
10th highest	2009/05/26 01:00	12,734	110	257	10.7	3.6	229	E	141

5 Conclusions

This assessment was performed as a conservative assessment to review the potential for air quality impacts associated with the proposed activities for the Whalers Way orbital launch complex. The assessment included both launch and engine tests events.

In considering the results the following should be noted:

- The emissions estimation was based on conservative emissions data and worst-case emissions for each pollutant.
- The emission rates for both launches and engine tests are high. However, they only occur for very short durations. For a launch event, emissions contributing to ground level concentrations only occur for up to 30 seconds and for engine tests, emissions only occur for up to 2.5 minutes.
- The operations plan for 36 launches and only a few engine tests per year. This means that emissions from site over a whole year are expected have a duration for less than an hour.
- The assessment considered emissions for every second hour of the year with modelling of 4,380 launches and engine tests respectively.
- An analysis of contribution to the ground level concentrations showed that the emissions closest to ground in stable conditions contribute to the most to the predicted highest concentration events. There is very little contribution to ground level concentration from emissions above 1,200 m.

Considering the relatively small number of launch and engine test events compared to the number of events assessed in all dispersion conditions it is unlikely that a launch or engine test would co-occur with the worst dispersion conditions and result in ground level concentrations as predicted. The emissions from the operations are expected to mostly occur in average dispersion conditions producing lower ground level concentrations than what was presented in the results.

The air quality impact assessment shows that there is a low risk associated with air quality impacts from the proposed orbital launch complex as assessed.

Should there be future plans for launches of much larger launch vehicles or engine tests of larger engines or with unusual fuels the emissions from the new operations should be reviewed and potentially assessed if there is reason for concern.

6 References

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APPENDIX A

Evaluation of Meteorological Data

Evaluation of Meteorological Data

The primary meteorological data parameters relevant for the dispersion are typically:

- wind (wind speed and direction)
- turbulence (atmospheric stability)
- mixing height (depth of turbulent layer)

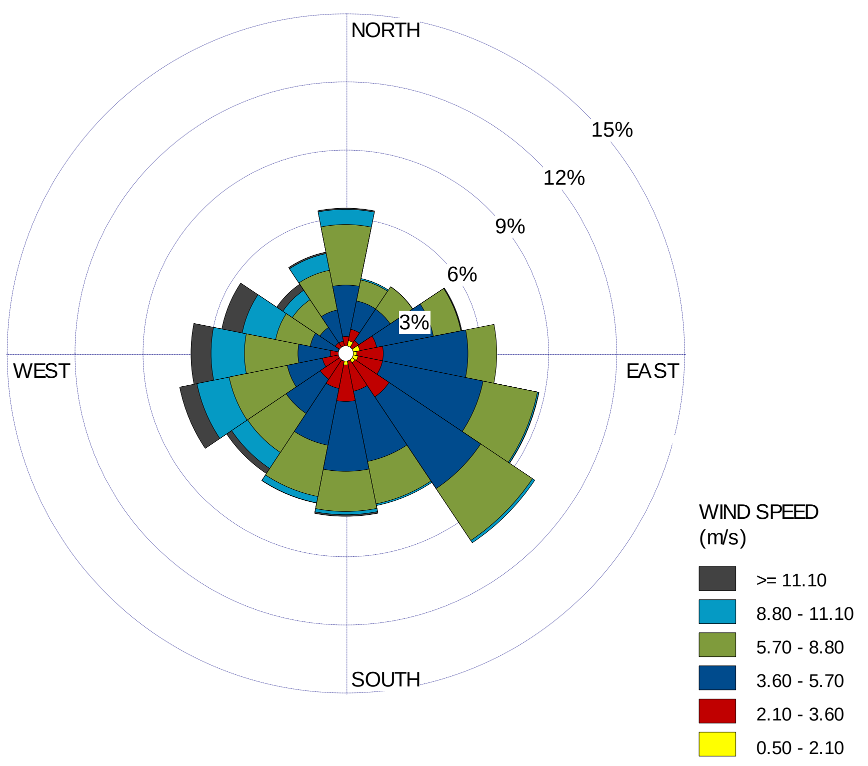
Evaluation of meteorological data for the above parameters extracted for the project location at Launch Site A is provided below.

Wind Speed and Wind Direction

Wind roses show the frequency of occurrence of winds by direction and strength. The bars show the direction the wind is blowing from and the lengths show the frequency of winds from that direction. The bars also show the wind speed categories for each direction with the frequency represented by the size of each bar with the lightest wind speed category closest to the centre of the wind rose.

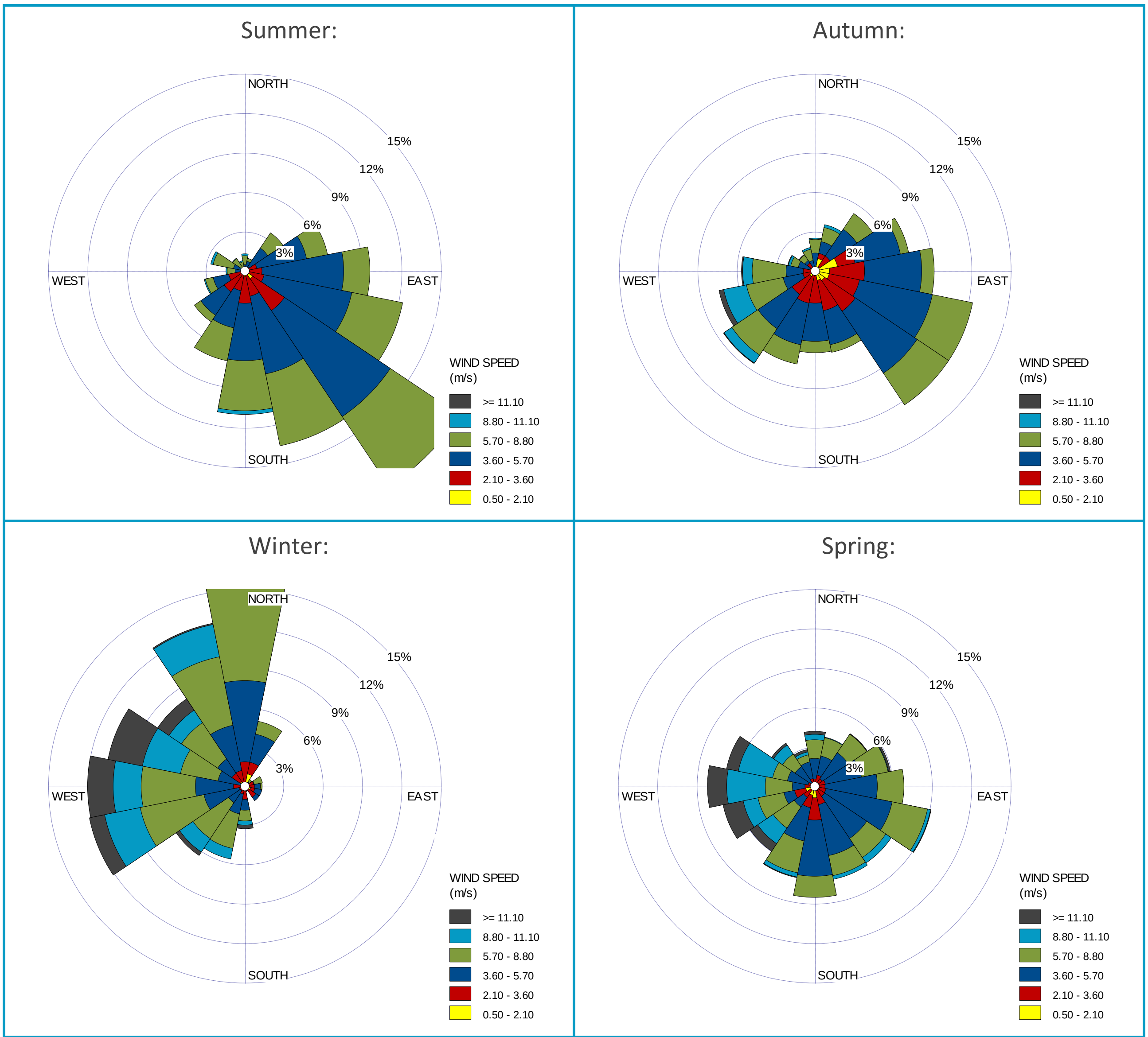
Wind roses are presented in **Figure 10** to **Figure 12** for the annual period of 2009 as well as for each season and time of day.

Figure 10 Wind Rose Project Site 2009



Location: Pad A	**Data period:** 2009	**Time period:** All hours	**Data type:** CALMET
Average wind speed: 5.53 m/s		**Calm wind frequency:** 0.42%	

Figure 11 Seasonal Wind Rose Project Site



Location: Pad A	**Data period:** 2009	**Time period:** Seasonal	**Data type:** CALMET

Average wind speed: Summer: 5.0 m/s Autumn: 4.6 m/s Winter: 6.7 m/s Spring: 5.9 m/s	**Calm wind frequency:** Summer: 0.56% Autumn: 0.54% Winter: 0.18% Spring: 0.41%

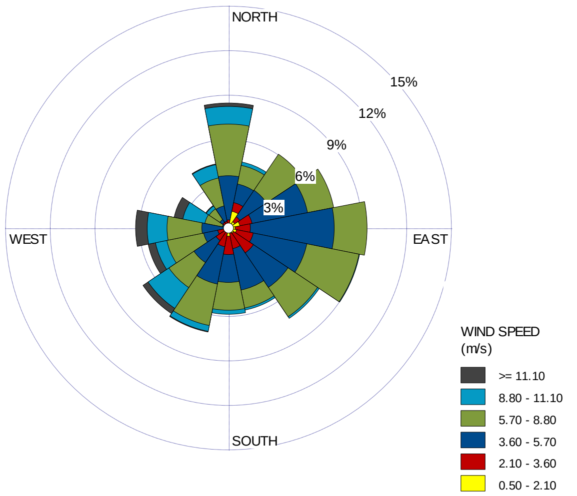
On an annual basis (**Figure 10**) the prevailing wind direction is from the southeast. The critical wind direction for exposure of the nearest sensitive receptors is from the southwest.

The seasonal data (**Figure 11**) show prevailing south-easterly winds in the summer and autumn months and prevailing northerly and westerly stronger winds through winter.

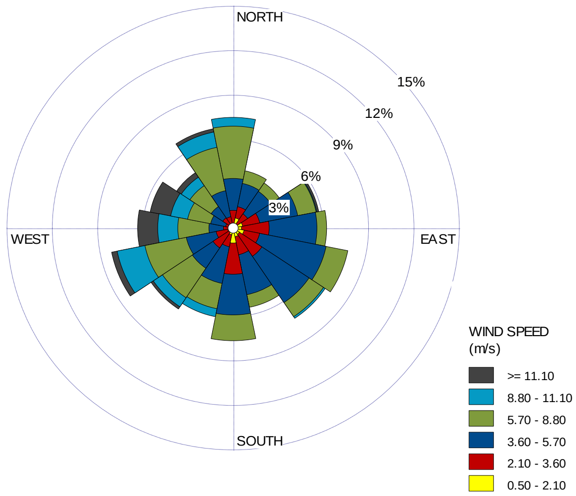
The time of day data (**Figure 12**) show prevailing south-easterly winds in afternoons and evenings. Overall, the wind data does not show unfavourable conditions and wind directions towards the nearest receptors.

Figure 12 Time of Day Wind Rose Project Site

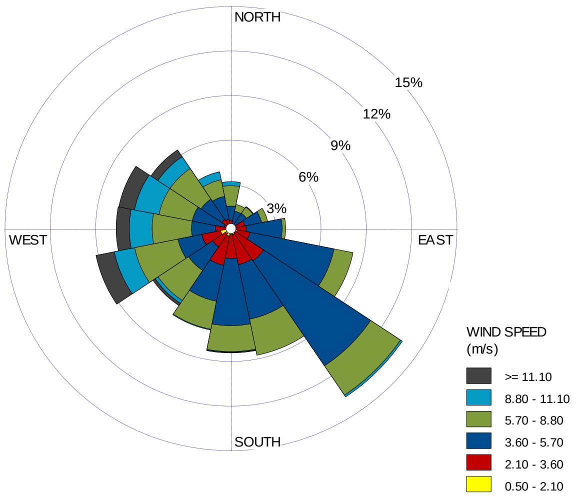
12 am to 6 am:



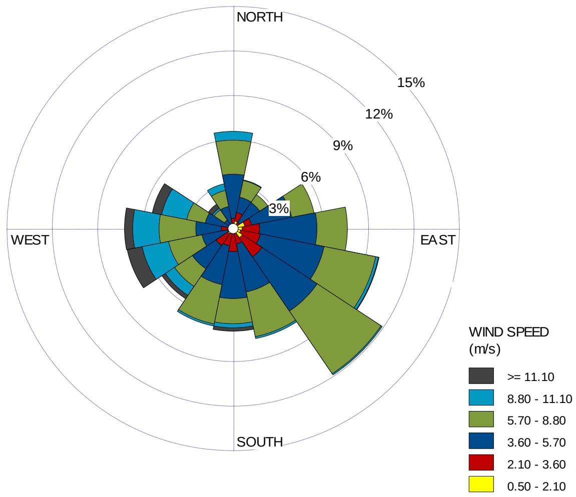
6 am to 12 pm:



12 pm to 6 pm:



6 pm to 12 am:



Location: Pad A	**Data period:** 2009	**Time period:** Time of day	**Data type:** CALMET

Average wind speed:
12 am to 6 am: 5.6 m/s
6 am to 12 pm: 5.4 m/s
12 pm to 6 pm: 5.5 m/s
6 pm to 12 am: 5.6 m/s

Calm wind frequency:
12 am to 6 am: 0.59%
6 am to 12 pm: 0.37%
12 pm to 6 pm: 0.18%
6 pm to 12 am: 0.55%

Atmospheric Stability

Atmospheric stability refers to atmospheric turbulence and the tendency of the atmosphere to resist or enhance vertical motion. Depending on conditions the atmospheric stability can either inhibit or promote pollutant dispersion. The Pasquill-Gifford scheme provides six stability classes, A to F, to categorise the degree of atmospheric stability as follows:

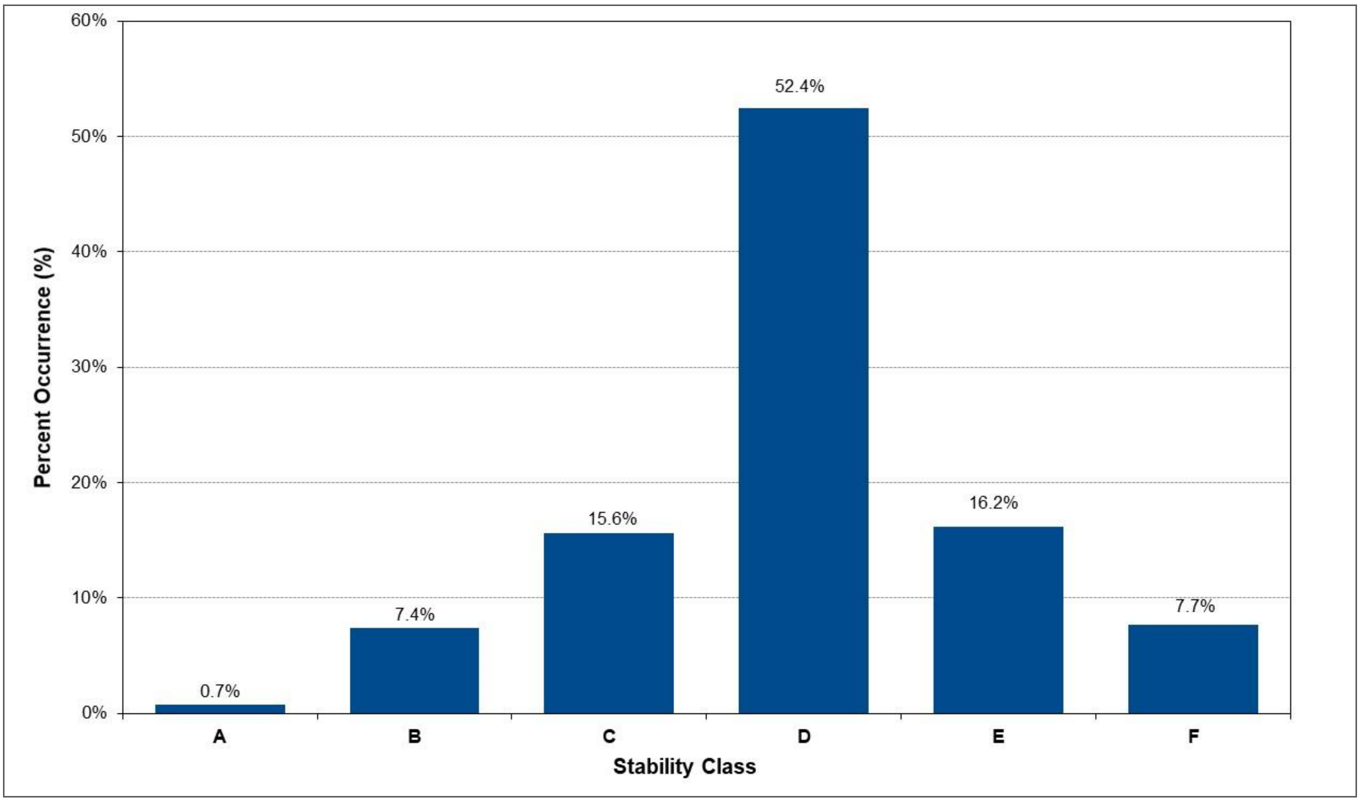
- A = Extremely unstable conditions
- B = Moderately unstable conditions
- C = Slightly unstable conditions
- D = Neutral conditions
- E = Slightly stable conditions
- F = Moderately stable conditions

Unstable conditions are favourable for dispersion and stable conditions are unfavourable for dispersion.

The dispersion modelling in CALPUFF used a more advanced atmospheric stability scheme (based on micro meteorology). Stability class data was extracted from the meteorological dispersion modelling data set for the meteorological data evaluation.

Stability class data as extracted for the project site are presented in **Figure 13** and shows a high frequency of D class stability which is typical for near costal settings.

Figure 13 Distribution of Atmospheric Stability Classes



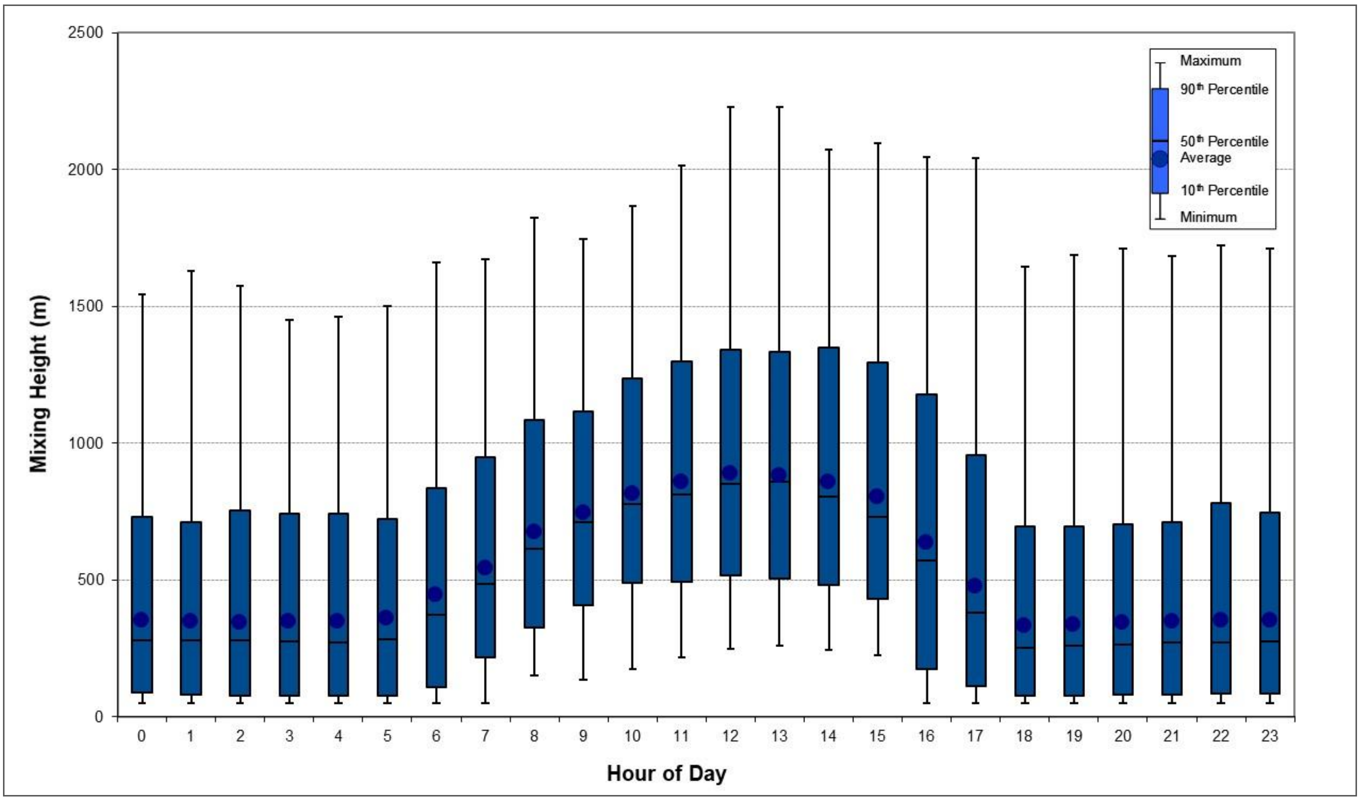
Mixing Height

The mixing height is the depth of the atmospheric mixing layer between ground level and an elevated temperature inversion. Depending on conditions vertical dispersion is typically limited by the mixing height. This is an important parameter in dispersion modelling since the mixing height largely sets the vertical profile the dispersion can take place in.

Mixing heights have a diurnal variation in response to mixing from convection due to insolation and grow from sunrise to around midday. Followed by a decline until sunset when there typically is a rapid decline. If a plume penetrates through, or is released above, the mixing height the pollutants will be trapped aloft with no mixing to ground level (unless in specific conditions such as fumigation). Similarly, if a plume is trapped below a low mixing height (inversion layer) the vertical dispersion will be limited, and higher ground-level concentrations are likely to occur.

The profile of the diurnal mixing heights predicted at the project site are presented in **Figure 14**and is consistent with near coastal locations.

Figure 14 Distribution and Statistics of Mixing Heights



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