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Australian Government
Department of Defence

REVIEW OF AUSTRALIAN SUPER HORNET AIR QUALITY MONITORING DATA

RAAF Base Amberley

FINAL

October 2021

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Prepared by

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on behalf of

Department of Defence

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1.0 Introduction

1.1 Background

On behalf of the Department of Defence (Defence) the Royal Australian Air Force (Air Force) operate RAAF Base Amberley, located on the outskirts of Ipswich, approximately 40 km southwest of Brisbane, Queensland. Among many other units, RAAF Base Amberley is home to 24 F/A-18F Australian Super Hornets (ASH), providing Australia with air combat capability. The ASH operate out of RAAF Base Amberley in accordance with an approval under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act). EPBC Approval 2008/4410 was granted on 23 March 2010 and has since been varied on 30 January 2012 and 23 April 2014. The Air Force is responsible for the implementation and management of the conditions associated with the operation of ASH.

Condition 4 of EPBC Approval 2008/4410 requires the preparation of an Air Quality Monitoring Plan (AQMP) that includes monitoring of air quality near a sensitive receiver in proximity to or on RAAF Base Amberley. Condition 4 also requires that the AQMP includes a process of validation of the accuracy of ASH air quality impacts as modelled in the Public Environment Report (PER) for the action dated November 2009.

The PER contained a section assessing the air quality effects of the proposal using CALPUFF, which is a computer-based air dispersion model. The model provided predictions of the concentrations of aircraft emissions in the Amberley area under the conditions expected to give rise to the highest concentrations of emissions; that is under conditions of maximum take-offs/landings per unit time and under worst-case dispersion conditions. The predicted concentrations were then compared with the relevant air quality assessment criteria for Queensland.

The PER predicted that ASH operations would cause only minor increases (compared with the assessment criteria) in pollutant concentrations at 17 selected sensitive receptor locations (see **Figure 3.1**). Further, when estimates of the existing background pollution concentrations were added to the predicted concentrations from ASH operations, the resulting concentrations would still comply with the Queensland assessment criteria.

As required by Condition 4 an AQMP was prepared and subsequently approved by DoEE on 29 April 2014. Air Force then commissioned AECOM to operate an ambient air quality monitoring station to measure and report on the parameters specified in the AQMP on behalf of Defence.

As detailed in the AQMP the data collected was to be used to assess the accuracy of ASH air quality impacts as modelled in the PER. The monitoring program commenced in June 2014. Three reports reviewing the monitoring data have been prepared by AECOM. These cover the periods June 2014 to May 2015, June 2015 to May 2016 and June 2016 to May 2017; AECOM (2015), AECOM (2016) and AECOM (2017).

It is understood that to date the approach taken in reviewing the monitoring data for the purpose of validating the PER modelling has been based on examining time-series plots of measured pollutant concentrations along with information on aircraft movements. The objective was to identify a relationship between aircraft movements and pollution levels. Presumably the intention would then be to use a quantitative relationship between aircraft movements and measured pollutant concentrations to assess the accuracy of the modelling used in the PER.

So far, this approach has been unsuccessful in reaching a conclusion to validate the PER Modelling. This is partly because the ASH movements have not reached the intensity (14 movements/hour) assumed for the worst-case situation in the PER and partly because the method is not able to separate the effects of emissions from ASH operations from the effects due to all other sources that contribute to pollutant concentrations at the air quality monitor. However, air quality monitoring to date and the AECOM time-series analysis has been successful in demonstrating the effect of emissions from ASH operations is small relative to the Queensland assessment criteria and that the assessment criteria are easily met with no exceedances recorded.

Essentially the PER modelling involved two parts; one the estimation of the concentrations resulting from ASH operations and two, the estimation of the background concentration, that is the effects of all other sources. The monitoring data that has been collected simply measures the combined effects of the ASH emissions and the background. An alternative approach is to attempt to quantify the ASH contribution to the monitoring data and compare this to the PER modelling to assess the accuracy of ASH air quality impacts as modelled in the PER.

1.2 Purpose and Approach of this Review

Air Force commissioned Umwelt to conduct a review and further analysis of the ASH Air Quality Monitoring Reports that have been prepared and to evaluate whether the monitoring data collected can be used to allow for validation of the accuracy of ASH air quality impacts as modelled in the PER.

This review has been completed by Nigel Holmes PhD who is an atmospheric physicist with over 40 years' experience in the use of computer-based air dispersion models to assess air quality impacts.

As noted in the previous section several challenges have been identified in using the data to validate the PER modelling. One of these is that the ASH activity is intermittent and only occurs for a very small fraction of the time and the air quality monitoring is only undertaken at one location which means it will likely take many years of monitoring before the right combination of conditions are met, that is, before the ASH movements are at their worst-case levels (14 movements/hour) and the wind is blowing from the correct direction to take emissions from the runway to the monitor and dispersion conditions are unfavourable. Therefore, direct monitoring of the impact as modelled (i.e. regular use at worst-case usage levels) is not considered practical and an alternative analysis method is required.

This review attempts a more detailed analysis of the data that has been collected to identify the relationship between ASH operations and air quality, that is it attempts to quantify the ASH contribution to the air quality monitoring data and to assess the accuracy of the PER modelling of the ASH contributions. In this regard several approaches are used in this review to explore ways of increasing the sensitivity of the analysis with the available data. These are described in the following sections and the findings of each are discussed.

It is concluded that the contribution that ASH emissions make to air quality at the monitoring site are very small compared with the background levels and are small compared with the Queensland assessment criteria with which the recorded emissions readily comply. This is the same conclusion as found in the PER and AECOM reports. However, there is at least one hour in the monitoring data that suggests that the contribution from ASH operations under worst-case levels of 14 movements/hour (if this was to ever be realised) could be higher than predicted by the PER modelling. This data point may be an anomaly and analysis of the second highest observation suggests the reverse, that is that the modelling is accurate and slightly conservative.

In summary, the objectives of this review are to:

- Assess the accuracy of ASH air quality impacts as modelled in the PER, using the existing monitoring data that has been collected as required by the AQMP, and
- Provide recommendations for the continuation of the ASH air quality monitoring program.

2.0 Relevant Points from the PER

The PER predicted the 'worst case' intensive hour air quality impacts by estimating emissions and air dispersion modelling for a single hour between 7 am (0700 hrs) and 12 am (0000 hrs) based on two operating scenarios as follows.

- 7 pairs of Super Hornets start-up, taxi out and take off on Runway 33; and
- 7 pairs of Super Hornets start-up, taxi out and take off on Runway 15 (reciprocal runway to Runway 33).

As noted previously, to date operations have not yet matched these worst-case modelling scenarios. This complicates the use of the monitoring data to validate the worst-case modelling from the PER.

In addition, there are other complications to validating the modelling, which are discussed in the following sections. To understand these, it is useful to explain the assumptions made in the PER and consider the reports, which analyse the monitoring data.

3.0 Background – Location of Runways, Air Quality Monitor, Meteorological Station

3.1 Local Setting

For completeness, this section presents information and figures extracted from the PER and from the air quality monitoring reports prepared by AECOM.

Figure 3.1 shows the Amberley Air Force Base and the locations of sites at which model predictions were made, the locations of the Bureau of Meteorology's (BoM) Automatic Weather Station (AWS) and AECOM 's air quality monitoring station. Also shown are the runways and taxiways used by ASH. The longer runways, Runway 33 and its reciprocal, Runway 15, are the two runways relevant for this review.

Over a typical year at Amberley Air Force Base, the most common winds are from the north-northeast and east (see for example Table 6 in the AECOM (2015) report). The air quality monitoring site is located to the southwest of the Runways 15 and 33 (see **Figure 3.2**) so is well-located to capture emissions from ASH operations while using the taxiways and during take-off and landing (i.e. is located within the prevailing wind axis).

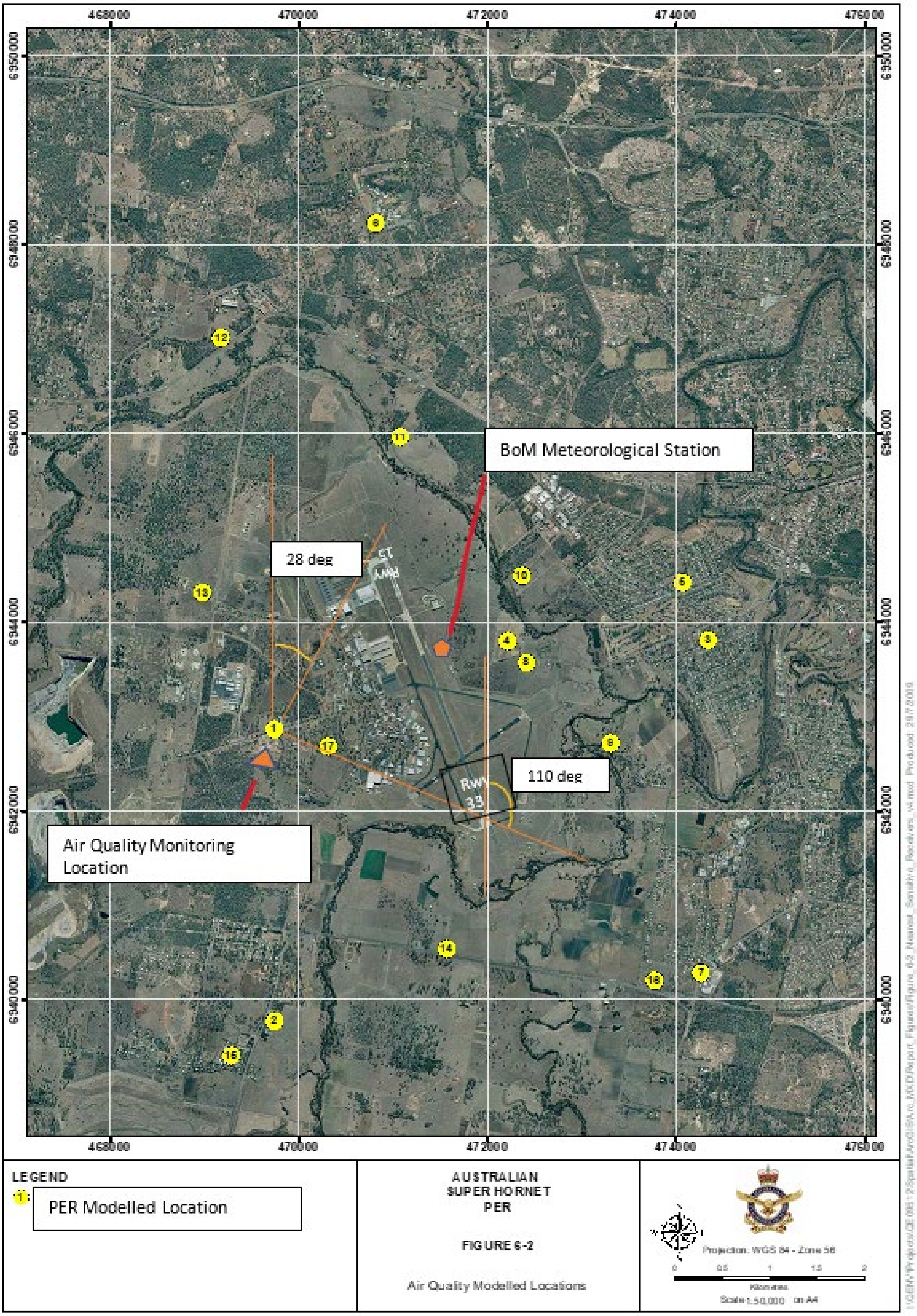

Figure 3.1 RAAF Base Amberley and Surrounds

(Adapted from Figure 6-2 in PER)

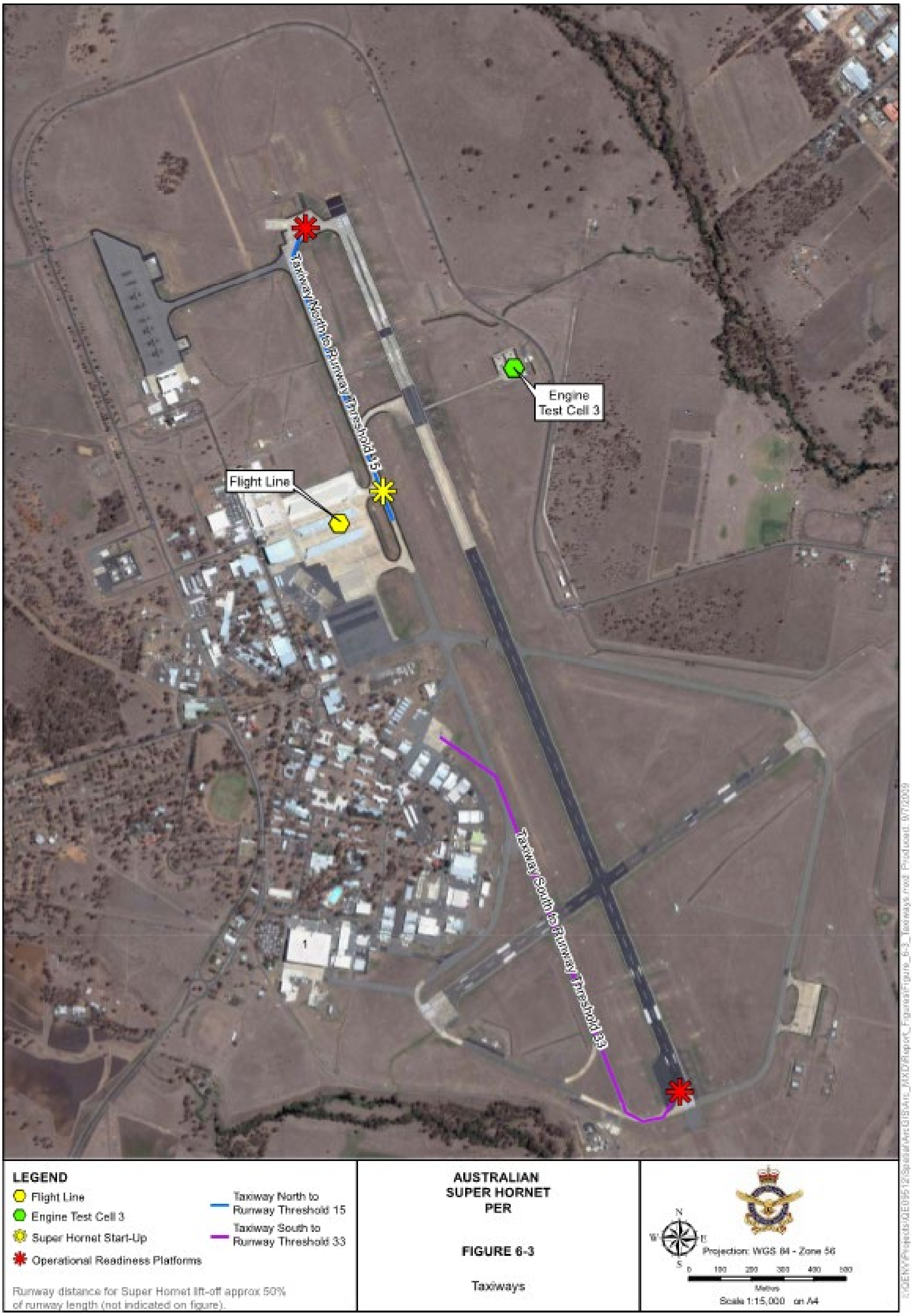

Figure 3.2 Zoomed-in view of RAAF Base Amberley

(Source: PER)

The PER describes the modelling undertaken in the air quality assessment. **Table 3.1** shows the estimated emissions of formaldehyde, CO, NO_x, SO_2 and PM_{10} associated with 4 take-off stages. Emissions of CO are significantly larger than any of the other emissions. Therefore, CO might be a better tracer than the other emissions when trying to identify the contribution that ASH emissions make to air quality at the monitor.

The objective is to identify a particular species of pollutant from a specific source against the background level produced by all sources excluding ASH. Thus, it is not only the rate of emission that is important, but also the background concentration of each pollutant. A better measure as to which is the better pollutant to use as tracer would be the ratio of the hourly average emission under the assumed worst-case emission conditions compared with the average background concentration of the same pollutant.

Table 3.1 Copy of Table 6-8 from PER

- **Table 6-8 Air Emission Rates (g/s) for 'Worst Case' Hour of Super Hornet Operations at RAAF Base Amberley**

Source	Emissions (g/s)				
	Formaldehyde	CO	NO_X	SO_2	PM_{10}
Start-to-taxi (idle)	8.70	154.2	3.2	0.4	9.8
Taxi-to-ORP (idle)	2.90	51.4	1.1	0.1	3.3
Time in ORP (idle)	2.90	51.4	1.1	0.1	3.3
Takeoff (A/B max.)	0.02	24.9	9.9	0.4	0.7

The relevant ratios are calculated below:

- CO background is 0.02 ppm (24.4 micrograms/cubic metre) compared with an emission of 281.9 g/s, which gives a ratio of 11.5 (g/s)/(micrograms/cubic metre)
- NO_x background is 0.006 ppm (8.94 micrograms/cubic metre)[1] compared with an emission of 15.3 g/s which gives a ratio of 1.71 (g/s)/(micrograms/cubic metre)
- SO_2 background is 0.000673 ppm (1.92 micrograms/cubic metre) compared with an emission of 1.0 g/s which gives a ratio of 0.52 (g/s)/(micrograms/cubic metre)
- PM_{10} background is 10.6 microgram/cubic metre compared with an emission of 17.1 which gives a ratio of 1.61 (g/s)/(micrograms/cubic metre).

The background concentrations used in the calculations above have been taken from the averages of over approximately 20,000 hourly observations from the AECOM data.

Given that all the emissions will be diluted by the same amount in dispersing from the emission point to the monitor, we can conclude that CO is the emission that would be easiest to detect above background concentrations. CO would be at least 6 times more concentrated relative to its background concentration compared with NO_x, 22 times more than SO_2 compared with SO_2 background and seven times more than for the PM_{10} background.

[1] Note: NO_x is a mixture of NO and NO_2. In converting the concentration of NO_x in ppb to micrograms/cubic metre it has been assumed that the average background NO and NO_2 concentrations are 1.8 ppb and 4.2 ppb respectively. These values were determined from the monitoring data.

This is not to say that CO emissions from ASH will be detectable above the background. It simply suggests that CO is the emission likely to have the strongest signal at the monitor relative to the background levels.

Note: the monitoring program also measured concentrations of formaldehyde and ozone (O_3). Because of the technology available for monitoring formaldehyde, no short-term average data are available and so this emission is not useful for analysis in this review. Ozone is not emitted directly from the Super Hornets and so this is also not useful for analysis in this review.

3.2 Data used in the analysis and the analysis procedures

The data available for this review were provided as computer files of:

- Hourly counts of arrivals and departures of Super Hornets for the period 1 June 2014 to 31 December 2017,
- Air quality monitoring data listing the hourly average concentrations of CO, NO, NO_2, SO_2, PM_{10} and $PM_{2.5}$ for the period 30 May 2014 to 1 April 2019; and
- 10-minute averages of wind direction, wind speed and temperature for the period 1 January 2014 to 31 December 2017 (provided by BoM).

The locations of the air quality monitoring site, BoM meteorological station and the runways are shown in **Figure 3.1**.

The 10-minute meteorological data were processed to calculate hourly average wind speeds and wind directions (vector averages). A single file showing the date, hour, corresponding wind speed, wind direction, ASH arrival and departure count and the concentrations of CO, NO, NO_2, SO_2 and PM_{10} and $PM_{2.5}$.

In creating the file any hour showing zero wind speed (that is calm), or missing CO concentration was excluded from the file. Wind direction is undefined under calm conditions and these data cannot be used in an analysis, which requires knowledge of the wind direction. As discussed earlier, CO has been used as a tracer of ASH emissions and so a valid measurement is required.

Some negative values of recorded concentrations were present in the AECOM data files. Negative values can arise in air quality monitoring data sets when the measured observations are at very low concentrations and within the noise floor of the instruments. Thus, electronic noise can result in a negative record when the actual concentration is close to zero. It is recommended in these cases to assume that it is just as likely that a small positive error is recorded as a small negative error. Provided these negative values are left in the record, the net result is for such errors to cancel. Thus, small negative values of pollutant concentrations were treated as valid observations (see AECOM reports for further discussion). In this review the data were used as provided by AECOM, that is the negative values were treated as valid observations. As will be seen later, the analysis in this review relies on comparing observations of pollutant concentrations occurring when Super Hornets were and were not operating. So provided both cases are treated the same the approach is appropriate.

The database was then used to produce pollution roses for each of the pollutants namely CO, NO_x (NO plus NO_2), SO_2 and PM10. $PM_{2.5}$ is a subcomponent of PM_{10} and was not analysed separately.

Pollution roses show the average or maximum pollutant concentration associated with a particular wind direction. For the pollution roses generated here, the wind direction was first re-classified as being in one of 36 sectors, each 10 degrees (^{o}) wide. The corresponding pollutant concentration for each sector was then read from the data file and the average and maximum value was determined. In the case of averages, the pollution rose then shows the average of the hourly observations associated with winds for each sector over the period covered by the database, which was approximately 20,000 hours of which 3,076 had at least one ASH movement.

For the maximum concentration roses, the diagrams show the maximum concentrations associated with each of the 36 wind direction sectors.

Not all hours had valid pollutant observations, that is not all the monitors worked all the time. The data set included 21,441 hours for CO, 19,296 hours for NO_x, 19,569 hours for SO_2 and 21,441 hours for PM_{10}.

Figure 3.1 shows that for aircraft emissions to be transported from the taxiways and runways to the monitor, the wind direction must be in the sector defined by a bearing of 28 ^{o} clockwise to 110^o (average 69^o). In practice, it is unusual for winds to be steady in either speed or direction over a period of an hour. Thus, it would not be surprising to see the pollution rose showing elevated concentrations for wind directions outside sectors defined by the geometry shown in **Figure 3.1**. However, if emissions are from the runway or taxiways, they should generally be associated with winds in this sector (28^o to 110 ^{o}).

4.0 Approach to the Analysis for this Review

For the reasons discussed previously, it is concentrations of CO that are of most interest to inform this review. The CO measurements have been made using an instrument with a full-scale range of 50 ppm and an uncertainty of ± 2.2% of the full-scale range (see Table 3 in AECOM (2015). Thus, the absolute uncertainty is 1.1 ppm.

The 8-hour air quality standard for CO is 9 ppm and so an uncertainty of 1.1 ppm is not a problem for ambient air quality monitoring. However, the predicted maximum increase in 8-hour average CO concentrations due to an assumed maximum of worst-case involving 14 ASH departures in an hour is about 0.13 ppm (based on predictions made at a nearby receptor). Thus, the expected concentration we are looking for is approximately a factor of 8 smaller than the uncertainty in the measured concentration. This means that the analysis has to be based on averages and not on individual readings, unless of course the modelling has grossly underpredicted, which is not the case.

It will be clear from the above and from later sections of this report that the challenge of using the monitoring data to quantify the contribution that emissions from ASH operations make to ambient air quality has parallels with signal processing in other fields; in particular with the problem of picking out a weak signal buried in noise.

A radio receiver does this using a filter centred on a particular frequency to extract a radio station signal and reject information at other frequencies. In addition, for repetitive signals, the sensitivity of the detection can be improved by averaging the signal over the repetition period. These are well-known techniques used in radio astronomy and other investigations where weak signals must be extracted from noisy data sets.

These principles have been applied to the Amberley data set where the equivalent of filtering has been done by focussing on a narrow band of wind directions and the averaging has been done by using many hours of data points. By doing this it has been possible to quantify the contribution that ASH emissions make to CO concentrations at the monitoring site.

5.0 Results

5.1 Analysis of Pollution Roses

A number of ways of analysing the data are presented in this section as, for the reasons explained in previous sections it is challenging to use the data that has been collected on its own to directly validate the accuracy of the air quality impacts that have been modelled in the PER. In this regard presenting multiple approaches provides some insight into the significance of the emissions and their effect on ambient air quality compared with background levels.

In assessing the accuracy of the air quality impacts modelled, we need an estimate of the highest CO concentration predicted at the monitoring site. The PER modelling does not provide a specific prediction for this site. The closest site is Site 17 (Amberley Child Care centre), which is predicted to experience a maximum increase in the 8-hour average CO concentration of 160 micrograms/cubic metre or 0.13 ppm. This modelling prediction of 0.13 ppm (averaged over 8-hours) will be compared with the estimated maximum monitored concentration from the analysis below.

Figure 5.1 shows the average of the hourly concentration of CO calculated by averaging the CO concentration for every measurement in the indicated wind direction sector.

The analysis shows two curves. One is constructed using data for the hours in which there was at least one ASH arrival or departure. The other is constructed using data for the hours when no ASH movements were recorded. The data show a wide scatter, but the average CO concentration is higher for hours when Super Hornets are active, and the wind direction is in the sector 350^{o} clockwise to 180^{o}. The sector contains the built-up areas to the northeast as well as the runways and taxiways. These areas would be expected to be sources of CO, but the fact that the averages for the hours when ASH movements are occurring are higher than when they are not indicates that the increase is due to emissions from the Super Hornets.

The data show concentrations are sometimes higher when Super Hornets are operating than when they are not, even when the average wind direction is outside the relevant sector. This is not unexpected. The average CO concentration and wind direction values are based on hourly averages. As noted previously, wind directions can vary significantly over an hour. Thus, over an hour, the minute-by-minute wind directions will not be precisely confined to the wind direction sector that is determined by the geometry depicted in **Figure 3.1** even when the hourly average wind direction is in the sector.

Note in the following discussion, the highest CO concentration of just under 0.108 ppm (**Figure 5.1**) has been disregarded. It is a consequence of an anomalously high measurement of 12.66 ppm occurring on 4 July 2014 during the hour ending 14:00 hours. There were no ASH movements at the time and so discarding this observation is reasonable.

Based on the data used to create **Figure 5.1**, it is estimated that in the hours when there is at least one ASH movement, the hourly average CO concentration is increased by approximately 0.016 ppm. Taking the pessimistic[2] assumption that this increase is caused by just one ASH movement, it would be concluded, that with 14 movements (the number of movements taken to be worst-case in the PER) the average increase in

[2] This is a pessimistic assumption given that we are wanting to show that the model is either accurate, or even better, that it overpredicts. If the increase of 0.016 ppm was because of "N" movements then the effect of one movement would be 0.016/N and the resulting estimate of the CO concentration for 14 movements would be lower than 0.224 ppm (14 x 0.016).

the CO concentration would be approximately 0.224 ppm. This is higher than the predicted worst-case (0.13 ppm) in the PER. Note, although 0.224 ppm is 72% above the worst case predicted in the PER, it is only 2.5% of the Queensland 8-hour assessment criterion of 9 ppm. Further it would require the 14 movements/hour to be repeated for continuous 8 hours while dispersion conditions remained in the unfavourable state that led to the 0.016 ppm concentration observed.

An alternative, less pessimistic estimate of the contribution the ASH emissions make to CO concentrations, can be made by examining the sector, 30-to-110°, and noting the number of hours that ASH were active (Tot_active_hours) and the total number of ASH movements in those hours (Tot_ASH_movements). This allows us to estimate the average number of movements associated with the average CO increase observed to be caused by the ASH movements.

Review of the raw data shows:

- Tot_active _hours = 1,128[3]
- Tot_ASH_movements = 4,696.

Thus, the average number of ASH movements, while the wind was in the 30 to 110° sector is, 4.2 (i.e., 4,696/1,128).

If the average increase in CO concentration at the monitor due to ASH emissions is 0.016 ppm and this is due to an average of 4.2 movements/hour, then the average increase per movement is 0.0038 ppm per movement or 0.053 ppm for the worst-case 14 movements/hour.

A concentration of 0.053 ppm is 41 percent of the model prediction of 0.13 ppm and 24% of the 0.224 ppm using the most pessimistic[2] calculation method. However, the model prediction is for an 8-hour averaging period whereas the estimate derived from the monitoring data are based on 1-hour data. If we interpret the worst-case emission scenario (14 movements in an hour) as being only one hour in the 8 hours, then the estimated 8-hour increase from the monitoring would be lower by a factor of almost 8. It would be theoretically possible, although extremely unlikely, that the worst-case 14 movements per hour occurred for every hour of the 8-hour period and that the meteorology maintained the same conditions for the 8 hours. If this were to be the case, then the 8-hour average CO concentration would be 0.053 ppm, that is still below the 0.13 ppm predicted in the PER.

This analysis suggests that the PER model is reasonably[4] accurate but tends to overpredict. It is noted that monitoring in the field is subject to a range of uncontrolled variables and therefore it is challenging to make highly accurate findings relating to specific activities. Therefore, it should be noted when reviewing this conclusion that the estimate of the increase in CO concentrations when Super Hornets are operating, and when the wind is favourable, is an average over all the relevant hours. It includes the worst-case hour from a meteorological point of view as well as a range of other dispersion conditions. The PER model predicts the worst-case emissions occurring simultaneously with the worst-case dispersion. Therefore, to add further robustness to this review, it was decided to look at the data in other ways to provide further rigor for the conclusion.

[3] The figures that follow here have been derived from the database that underpins the plots show in Figure 5.1.
[4] For readers familiar with dispersion modelling, the term “reasonably accurate” could be replaced by “impressively accurate”.

Figure 5.2, **Figure 5.3**, and **Figure 5.4** show similar plots to those developed for CO except for NO_x, SO_2 and PM_{10}, respectively. These plots show some directional dependence in the concentrations of NO_x, SO_2 and PM_{10}, but there is no clear association with the movements of the Super Hornets. As discussed previously, this is likely because the concentrations resulting from the emission, relative to the background concentrations of these pollutants, is very small and is less than is the case for CO.

Given that the effect of the emission from ASH operations is not identifiable above the noise[5] in these (non-CO) cases there is no point in attempting to correlate the ASH movements with the measured concentrations of NO_x, SO_2 and PM_{10}. The concentration will be buried in the noise arising from background sources.

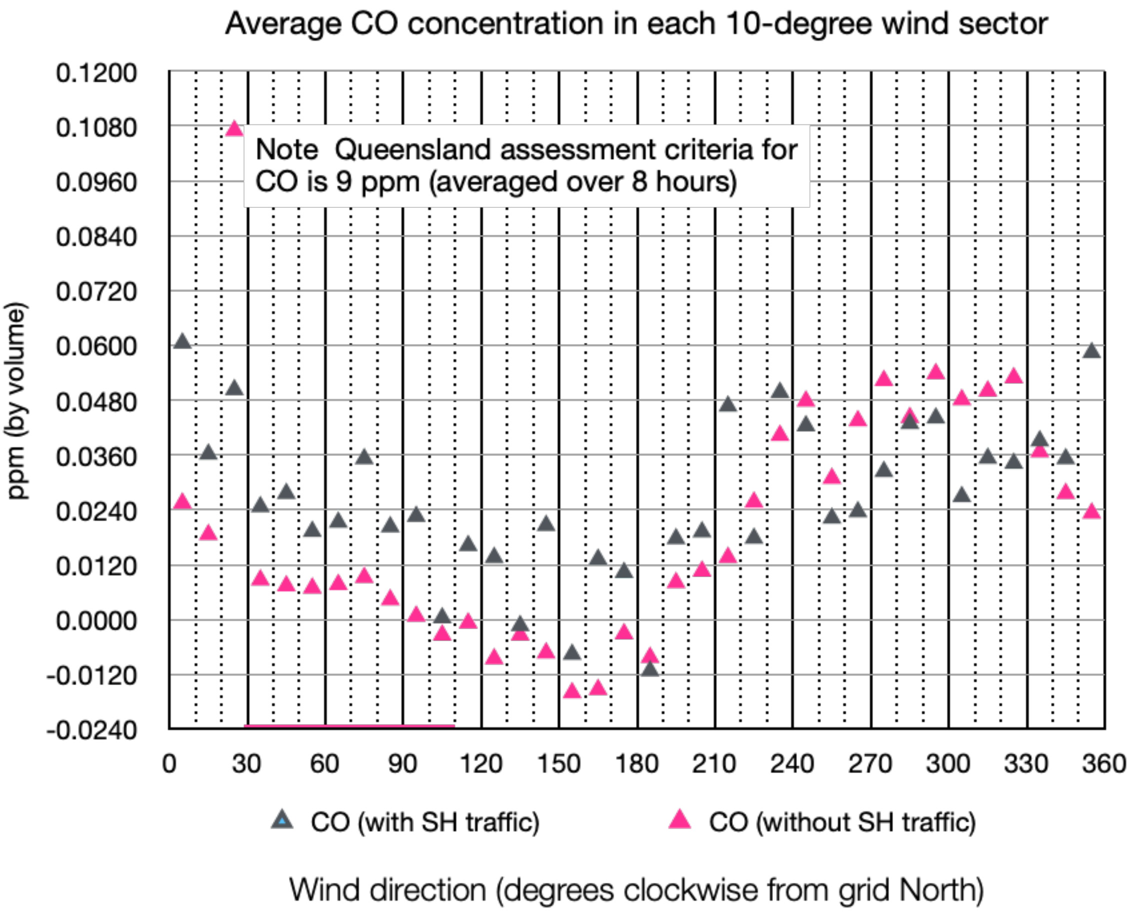

Figure 5.1 **Average of hourly CO concentrations against wind direction**

[5] A plot of background pollutant levels shows randomly fluctuating values. This is referred to as noise. A small addition to the pollution levels may not be noticeable among the fluctuating values. Such an emission would be said to be buried in the noise.

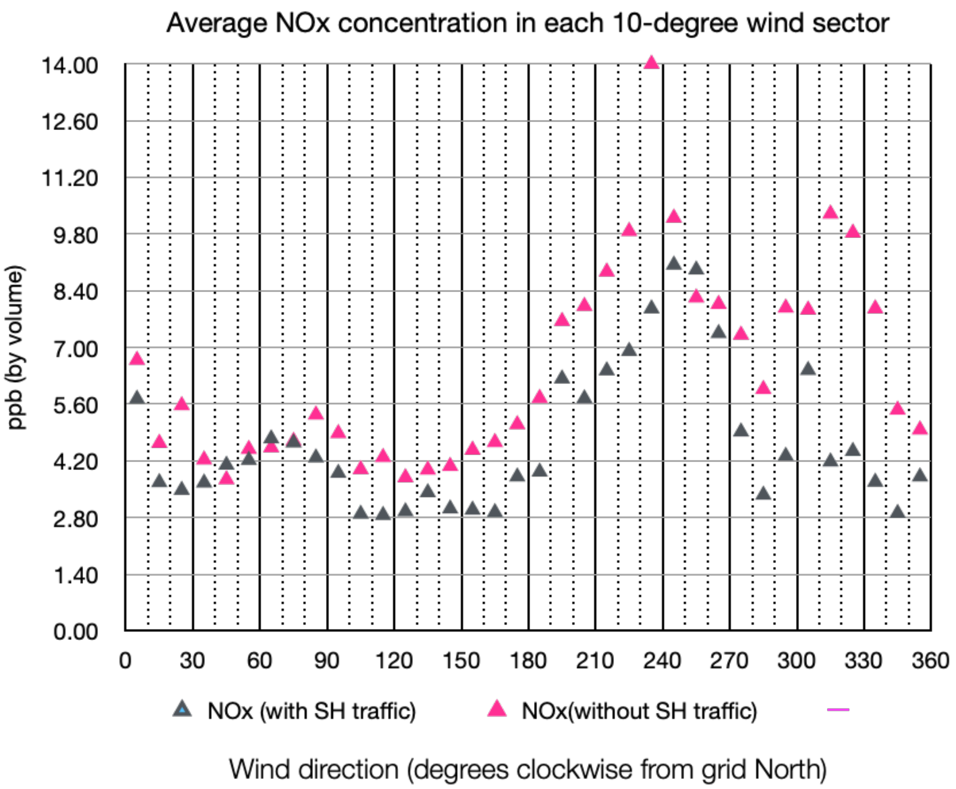

Figure 5.2 Average NO_x concentration against wind direction

(Note: no assessment criteria for NO_x)

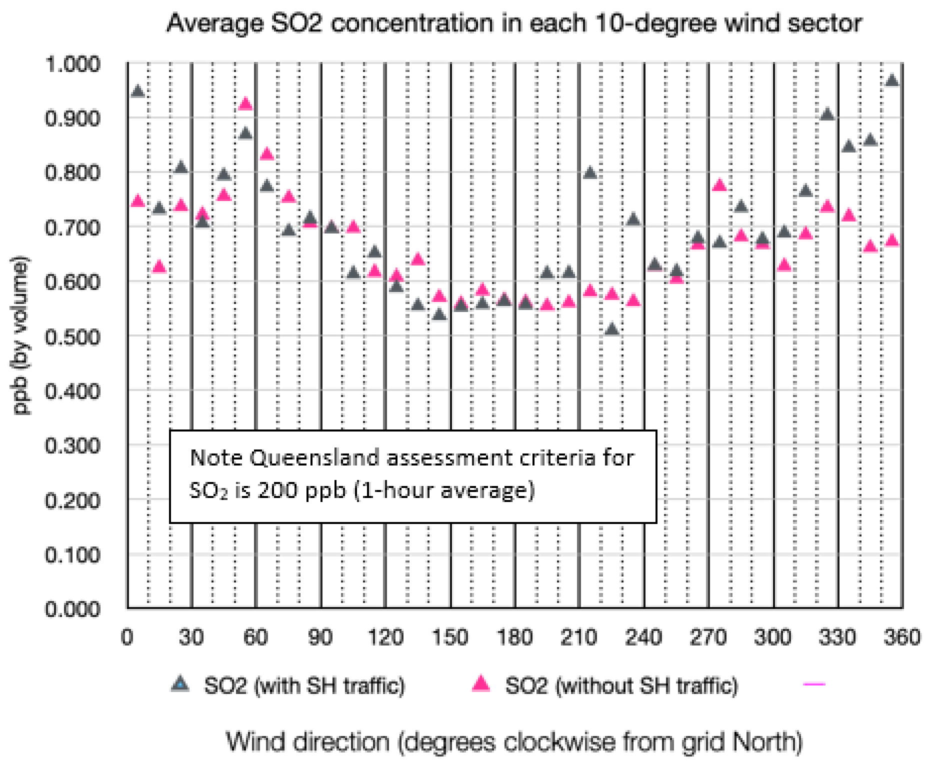

Figure 5.3 Average SO_2 concentration against wind direction

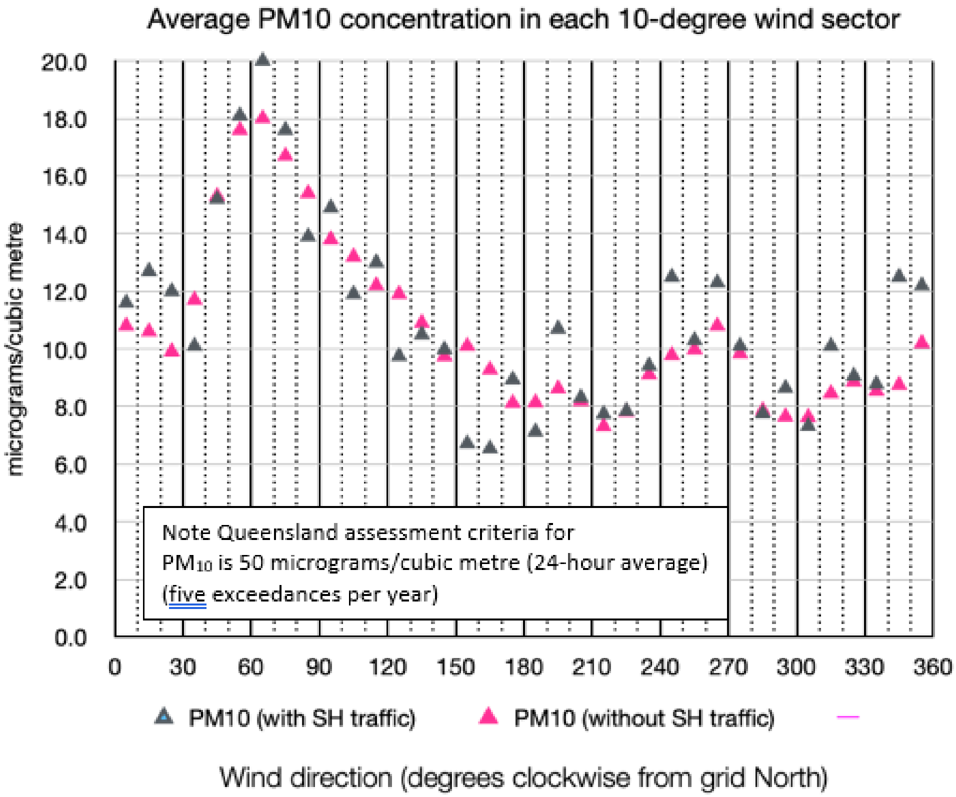

Figure 5.4 **Average PM10 concentration against wind direction**

5.2 Maximum Concentrations

Figure 5.5 and **Figure 5.6** show the maximum 1-hour average concentration of CO associated with each ten-degree wind sector. In the case of **Figure 5.6** the anomalous 12.66 ppm data point has been removed to show more clearly the difference between the cases when ASH were active and when they were not active.

Figure 5.7, **Figure 5.8** and **Figure 5.9** show the maximum 1-hour average concentrations for NO_x, SO_2 and PM_{10} respectively. The data points show a wide scatter and in many cases the concentrations are greater with the ASH not operating compared with hours when they are. This is likely to be because there are many more hours when ASH are not operating than when there are. If the ASH contribution is negligible, then the more hours that are considered, the more likely it is that an hour with a high concentration will be recorded.

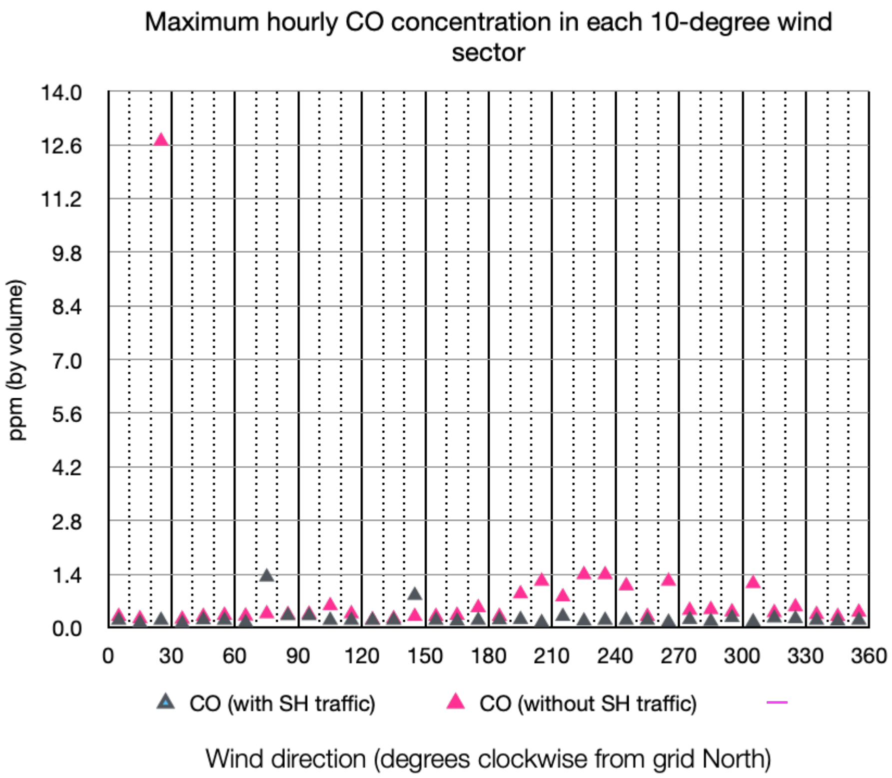

Figure 5.5 Maximum 1-hour average CO concentration against wind direction

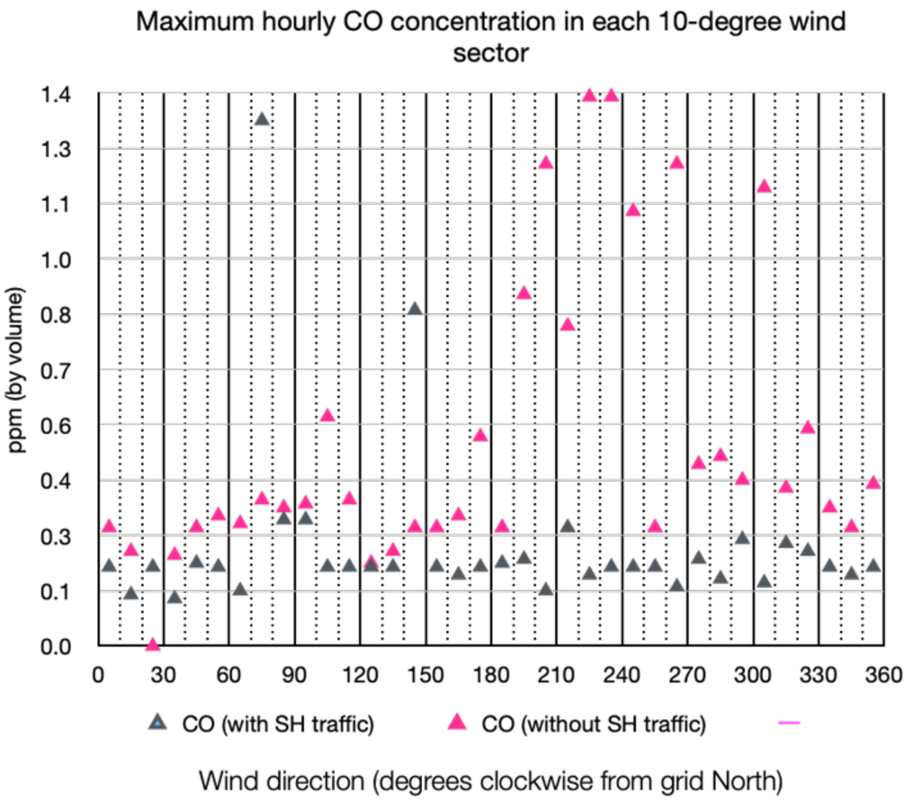

Figure 5.6 Maximum 1-hour average CO concentration against wind direction
(with anomalous datum removed)

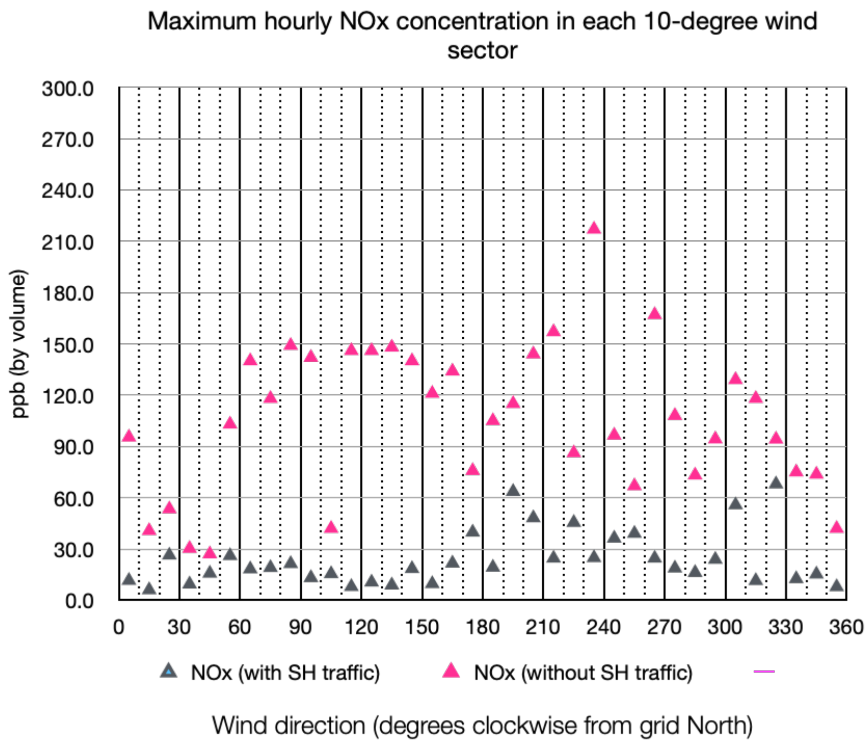

Figure 5.7 Maximum 1-hour average NO_x concentration against wind direction

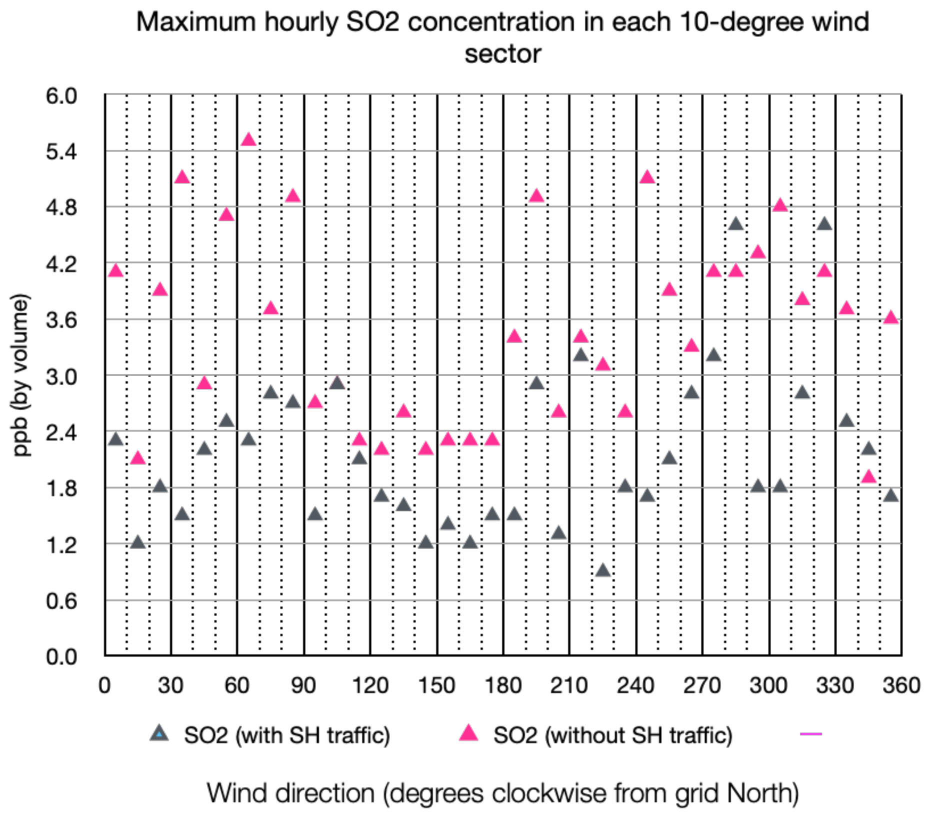

Figure 5.8 Maximum 1-hour average SO_2 concentration against wind direction

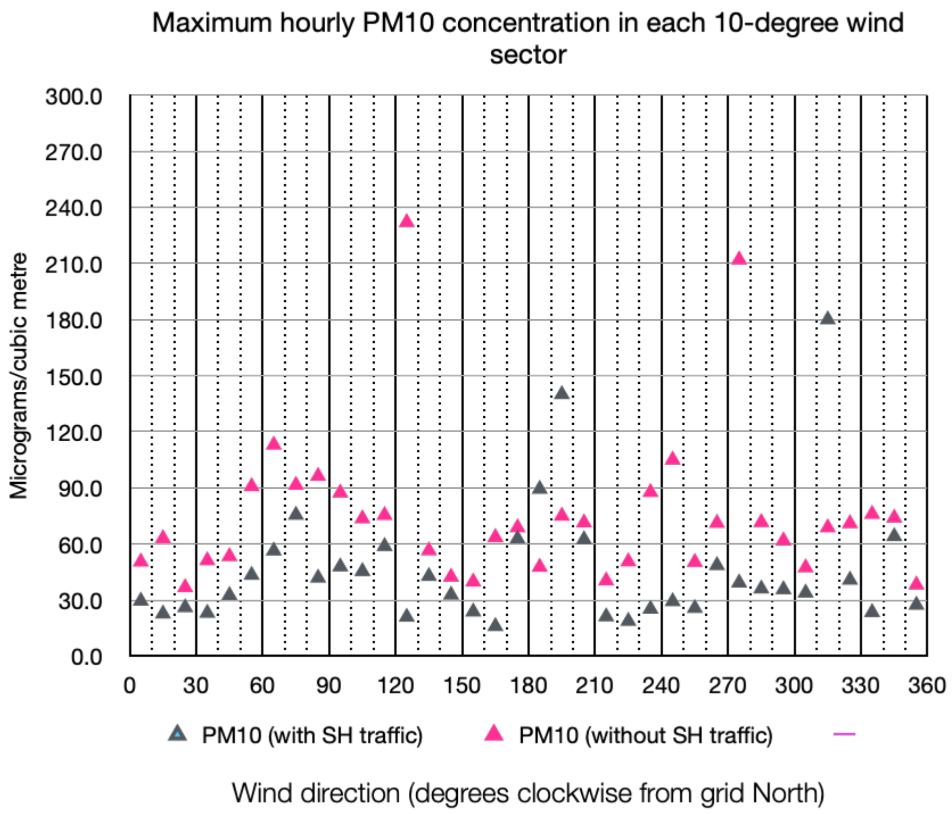

Figure 5.9 **Maximum 1-hour average PM_{10} concentration against wind direction**

5.3 Analysis of Days with High ASH Movements

The analysis in **Section 5.1** suggests that it might also be useful to examine the database to look for periods with high ASH movements and meteorological conditions that would transport emissions to the monitoring site.

June 30, 2016 is a candidate day. Over the day there were 16 ASH departures and arrivals (32 total movements). In the hour leading up to 19:00 hours there were 10 departures and no arrivals. This is close to the 14 movements taken to be the worst-case emission case in the PER modelling. Further, the hourly average wind direction was from 74°, and the hourly average wind speed was 1.8 m/s. Note, the midpoint of the active runways from the air quality monitor has a bearing of 68°, which means the emission sources (departing aircraft) were almost directly upwind of the monitor.

These meteorological conditions (light winds during the evening) would correspond to relatively poor dispersion. Conventionally, modelling for worst-case impacts involves running the model using a year of hourly meteorological data assuming worst-case emissions for the relevant hours. The meteorology that gives rise to the worst-case impacts will vary for each receptor.

Invariably, the most important meteorological parameter in determining concentration experienced at a particular receptor is wind direction. Wind speed and the intensity of turbulence are also important. In the case we are considering, the wind was light, and convection and hence turbulence would have moderated by 19:00 hours and so the conditions would likely favour poor dispersion.

The corresponding hourly average CO concentration was 1.33 ppm. The background concentration is unknown, but an estimate can be made by taking the average concentration observed in the hours when there were no ASH movements. The average background was 0.14 ppm (calculated from only 8 hours on that day when there were no ASH movements). Thus, the contribution to CO concentrations from the 10 ASH departures is estimated to be 1.19 ppm (1.33 – 0.14 ppm). This is equivalent to 1.67 ppm, if pro-rated to 14 movements/hour as assumed for the worst-case in the PER.

If the estimated 1-hour concentration of 1.67 ppm derived from the monitoring were to apply for only 1-hour in the 8 hours that the prediction applied to, then the average increase in the 8-hour CO concentration due to the ASH movements would be 0.21 ppm (1.67/8). Although this is only 2.3% of the 9 ppm 8-hour assessment criteria, it is still above the predicted 8-hour average of 0.13 ppm.

This analysis suggests that the PER model might have underpredicted. This is in contrast to the conclusion in **Section 5.1**. However, the analysis also shows that it is inconceivable that the ASH movements would cause any of the air quality assessment criteria for Queensland to be exceeded. Indeed, for NO_2, SO_2 and PM_{10} the effects of ASH emissions are effectively below the noise and the monitoring program as configured will never be able to detect emissions of these from ASH operations.

It is difficult to know how much weight to give to this analysis. The observed concentration of 1.33 ppm can be taken as a reliable observation, but the estimated background in the absence of ASH movements is possibly less reliable, being based on only 8 hours including many hours when the wind direction was not in the 28 to 110^o sector.

5.4 CO Concentrations Versus ASH Movement Data

Another approach to the analysis is to review the CO monitoring data to see if there is any detectable relationship between CO concentrations and the intensity of ASH movements.

Figure 5.10 and **Figure 5.11** are scatter plots of the 1-hour average CO concentration plotted against ASH departures in the same hour. **Figure 5.10** selects data for periods when the hourly average wind direction was in the sector 28^o clockwise to 110^o, which is the sector that transports ASH emissions to the monitor.

Figure 5.11 is a similar plot but uses only those hours with wind directions that would not transport emissions to the monitor.

In **Figure 5.10** there is one concentration measurement of 1.33 ppm associated with 10 departures. This occurred on 30 June 2016 at 19:00 hours.

This observation has already been analysed in **Section 5.3**, in which the measurement (or at least some of the measurement) was attributed to emissions from the Super Hornets, and it was concluded that the maximum CO concentration predicted in the PER of 0.13 ppm may have been exceeded on this day if pro-rated from 10 movements to the 14 movements assumed by PER as worst case. However, as seen in **Figure 5.10**, the value of 1.33 ppm appears to be an outlier. It is a factor of more than 4 higher than the next highest value. This fact was not obvious from the way that the data point was selected in **Section 5.3**. The next highest CO concentration associated with 10 departures was 0.15 ppm. This occurred on 16 May 2016 in the hour leading up to 14:00 hours and was associated with a wind with speed 2.7 m/s from 77^o, that again places the ASH emission sources directly up wind of the monitor.

Therefore, it is appropriate to examine both the outlier and the next highest observation. In the case of the 1.33 ppm outlier observation, we need to obtain an estimate of the background in the absence of ASH departures. To do this, we have taken the average of 8 hourly CO concentration observations made on the 30 June 2016 when there were no ASH movements. The value was 0.14 ppm

Therefore, the estimated 1-hour average contribution from the ten ASH departures is 1.19 ppm (1.33 – 0.14). This corresponds to 1.66 ppm for 14 departures. This can be compared with the 0.13 ppm predicted increase in 8-hour average CO concentrations in the PER and the 0.11 ppm estimated in **Section 5.1**. As in **Section 5.1** the maximum hourly value of 1.66 ppm becomes 0.21 ppm when there is only one set of 14 departures in 8 hours, or 0.42 when there are two sets and so on. Thus, based on the outlier observation, the model is under predicting the effect of ASH emissions. So based on the analysis of this event, we reach the same conclusion as in **Section 5.2**.

If the next highest measured CO concentration is taken, the concentration is 0.32 ppm which was measured with 8 departures. This occurred on 17 November 2016 in the hour leading up to 15:00 hours. The background has been taken to be 0.30 ppm which is the average of 8 x 1-hour average values. Thus, the estimated contribution made by the Super Hornets to the 1-hour average CO is 0.02 ppm for 8 departures. If this is pro-rated to 14 departures it gives 0.035 ppm. This is less than the predicted 8-hour CO average of 0.13 ppm from the PER. Arguing as in **Section 5.3**, if the estimated 1-hour concentration of 0.035 ppm were to apply for only one hour in the 8 hours that the prediction applies to, then the average increase in the 8-hour CO concentration due to the ASH movements would be 0.0043 ppm (0.035/8). If there were to be 2-hours in the 8 each with 14 departures the result would be 0.0088 ppm and so on. (The meteorological conditions would of course need to remain unchanged). These values will always be below the modelled predicted maximum 8-hour CO concentration of 0.13 ppm. Therefore, it is not unreasonable to conclude that this analysis (based on the second highest) shows the model to overpredict. As before the calculation rests on the estimated background concentration being accurate.

It is interesting to compare **Figure 5.10** with **Figure 5.11**. **Figure 5.11** shows the same information except with the wind directions that would carry ASH emissions to the monitor excluded. In case of zero departures, the observed concentrations show a wider spread and includes many cases when the concentrations are higher than when the Super Hornets are operational. This almost certainly because the contributions that ASH emission make to air quality are small compared with the totality of all other sources and because there are many more hours when there are no ASH operations than there are when the Super Hornets are active. This is the same point that has been made before with other presentations of the data.

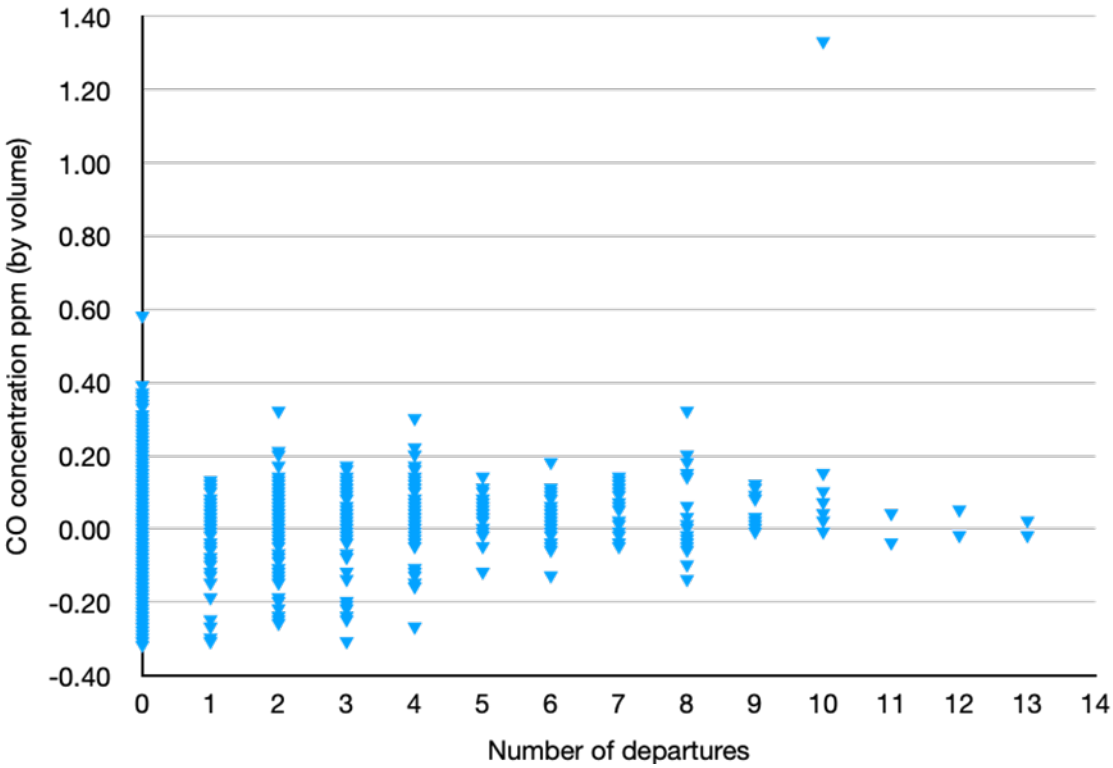

Figure 5.10 1-hour average CO concentration versus ASH departures with winds in the sector 28 clockwise to 110°

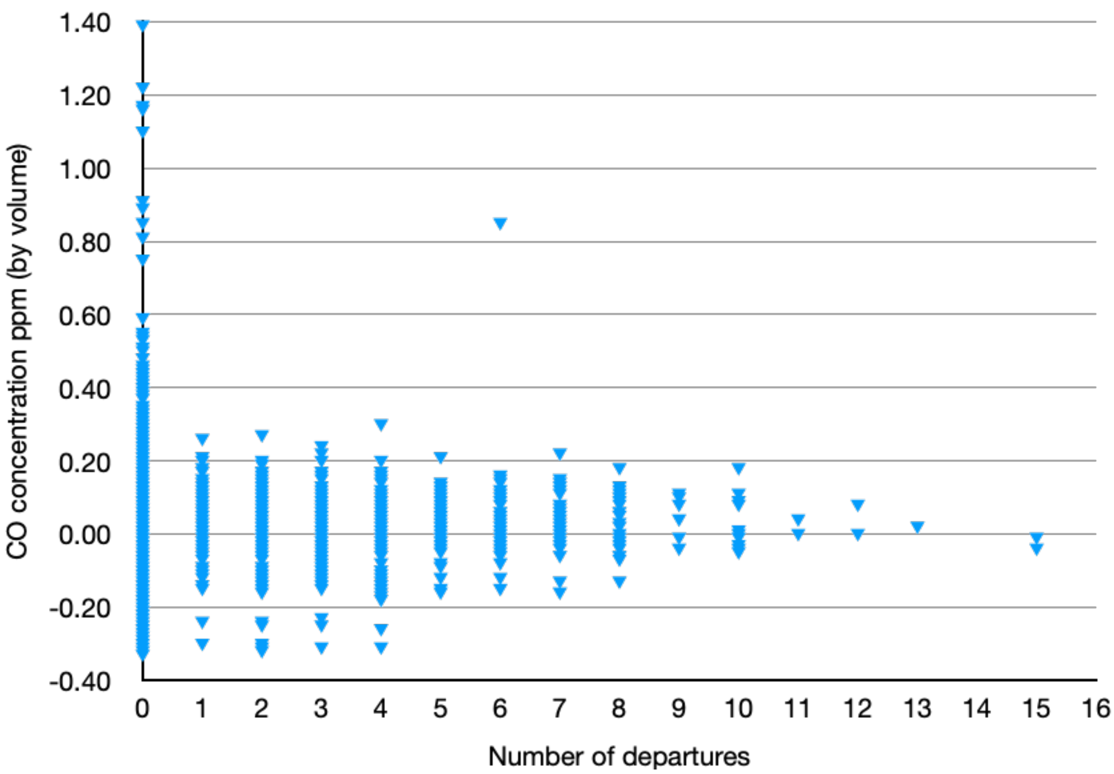

Figure 5.11 1-hour average CO concentration versus ASH departures with winds outside the sector 28 clockwise to 110°

6.0 Conclusions and Recommendations

This review has examined a database comprising hourly observations of wind speed, wind direction, counts of ASH movements and concentrations of CO, NO_x, SO_2 and PM_{10}. The objective has been to assess the accuracy of modelling of air quality impacts presented in the PER, which predicted the increase in pollutant concentrations due to emissions from a proposed worst-case operating scenario.

The worst-case modelling envisaged that for each hour between 07:00 hours and 24:00 hours the following two scenarios:

- 7 pairs of Super Hornets starting up, taxiing out and taking off on Runway 33, and
- 7 pairs of Super Hornet starting up, taxiing out and taking off on Runway 15.

As described in the sections above due to the many variables encountered during monitoring and the transient nature of ASH operations it has not been possible using the monitoring data to directly validate the PER modelling. However, it can be concluded that the PER air quality model predictions as to the contribution made by ASH operations are of the correct order and are so small that there is no risk that they would cause the Queensland air quality assessment criteria to be exceeded.

The reasons for the difficulties in directly validating the accuracy of air quality impacts modelled in the PER using the monitoring data are:

- Even though a substantial record of monitoring data is available there have been no hours where the worst-case operations (as envisaged in the PER) have been realized
- The predicted increases in pollutant concentrations at the monitoring site and the measured concentrations are very small compared with existing background concentrations due to other sources, and
- The accuracy of the concentration measurements is less than the predicted and estimated concentrations.

This review has concluded that the concentrations of NO_2, SO_2 and PM_{10} due to the ASH operations at the monitoring site are so low that they cannot be detected above the existing background level of these pollutants, and so are not considered of concern.

It has however proved possible to identify emissions of CO from ASH operations above the background concentrations. To do this it is necessary to carefully filter the data to calculate CO concentrations associated with winds in specific sectors. If the average concentrations associated with winds from the operating taxiways and runways, are compared with periods when Super Hornets are operating and periods when they are not operating, then the CO from the Super Hornets can be detected above the background.

By examining the periods when ASH movements are relatively high, and wind directions are aligned so that they transport emissions from the aircraft to the monitor, it has been possible to obtain an approximate estimate of the concentration of CO due to the operation of Super Hornets during a busy hour and under unfavourable dispersion conditions. Several events have been examined and it has been identified that estimated CO concentrations are very low when compared with the Queensland assessment criteria, but they could give rise to CO concentrations above the very low levels predicted in the PER for worst-case conditions (i.e., intense operations combined with poor dispersion). When assuming the worst-case operation levels, the CO concentration at the monitoring site due to ASH operations could be as high as 1.67 ppm. This is nearly 13 times the predicted worst-case (0.13 ppm) in the PER but is less than $^{1}/_{5}$ of the Queensland 8-hour assessment criterion of 9 ppm. Further, for this to be realised would require 14 movements per hour, repeated for 8 continuous hours while dispersion conditions remained in an unfavourable state. This is considered an extreme worst-case scenario.

Continuation of the monitoring in its current form is unlikely to ever provide the data that will prove unequivocally that the model predictions are accurate or conservative. However, the very detailed analysis of the monitoring data undertaken by this review confirms that the PER predictions of the worst-case concentrations of emissions from ASH operations under realistic worst-case assumptions are likely to be of the correct order and are very small compared with existing concentrations and that Queensland's air quality assessment criteria will not be exceeded due to ASH emissions.

The requirement that a monitoring program be established to validate the model predictions possibly did not envisage the difficulty of identifying the extremely small increments that the ASH operations would make to pollutant concentrations compared with the effect of other sources. This is the case even though background concentrations are low and local air quality is good.

In summary, as identified by this review, direct measurement and therefore validation against the PER modelling as to the emissions contribution from ASH operations is not practicable due to the small (sometimes nearly untraceable) contributions from them and the effect of other emission sources affecting monitoring results. The review confirms however from over 21,000 hours of air quality monitoring data that impacts are small, the Queensland criteria are readily complied with and that the overall findings (i.e., order of magnitude of air quality impacts predicted by the PER) are accurate and that ongoing monitoring isn't necessary to confirm or further validate these findings. In this regard monitoring to date has already demonstrated this outcome and the continuation of the air quality monitoring program is not considered to be warranted.

7.0 References

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