MWH

BUILDING A BETTER WORLD

14 October 2015

Horowhenua District Council
Private Bag 4002
LEVIN 5540

Attention: Warwick Meyer

Dear Warwick

Continuous Ambient Air Quality Monitoring for Hydrogen Sulphide September 2015—Levin Landfill

MWH New Zealand Limited (MWH) was engaged by the Horowhenua District Council (HDC) to measure ambient concentrations of hydrogen sulphide (H_2S) at the leachate pond located at the Levin landfill (hereafter 'the monitoring location'). The landfill is located at 665 Hōkio Beach Road, Levin, approximately 6 km to the west-north-west of Levin town centre, and covers an area of approximately 72 hectares (ha). The landfill is located in undulating sand dune country and is surrounded by pastoral farming. The monitoring was undertaken over a continuous period of one month between 11:08 am on 13 August 2015 and 8:55 am on 11 September 2015 (30 days). The results of the monitoring are presented in this letter.

H_2S was used in the present monitoring study as an indicator determinant of odorous compounds which have the potential to be discharged to air during activities currently undertaken at the landfill and, in particular, during the planned desludging activity which took place at the leachate pond between 12 August and 28 August 2015 (i.e. coinciding with the monitoring study detailed herein).

Reference should also be made to MWH's report entitled *'Levin Landfill Odour Assessment'* dated February 2015 and MWH's letter report dated 10 July 2015. The latter presented the results of a three month monitoring study for H_2S at 645 Hōkio Beach Road (or sensitive receptor 'R1') between 17 March 2015 and 18 June 2015. Sensitive receptor R1 was referred to in MWH's odour assessment report, and is situated approximately 90 m north-east of the Levin Landfill site boundary at 349021 metres east, 5503599 metres north (UTM Zone 60 South; or latitude 40.60467 degrees south, longitude 175.21545 degrees east).

MWH acknowledges the assistance provided by HDC and AirQuality Limited (AirQuality), and also the use of the *'openair' R* package for air quality data analysis (Carslaw and Ropkins, 2012). *R* version 3.2.2 and *openair* version 1.6 were used in this study.

1 Methodology

An API 100E ultraviolet (UV) fluorescence sulphur dioxide (SO_2) analyser coupled to an API M501 catalytic H_2S oxidiser with an Environics 6103 gas calibrator and an Ecotech zero air scrubber was used in this study. The instruments were housed in an air-conditioned enclosure held to 20 °C. The enclosure was situated on the northern boundary fence surrounding the leachate pond at 348868 m E, 5503279 m N (UTM Zone 60 South; or latitude 40.607499 °S, longitude 175.213585 °E), which was approximately 360 m south-west (SW) of receptor R1 and approximately 5 m from the pond. The monitoring site location is shown in **Figure 1**.

The sampling port was positioned at a height of 2 m above ground level. An ultrasonic anemometer was co-located with the sampling port and was used to measure wind speed and direction at a height of 2 m above ground level. In addition, ambient temperature, relative humidity and atmospheric pressure were

MWH New Zealand Limited
MWH House Level 3
111 Carlton Gore Road
Newmarket, Auckland 1023
PO Box 9176
Newmarket
Auckland 1149
TEL +64 9 580 4500
FAX +64 9 580 7600
www.mwhglobal.co.nz

also measured. This is the same instrumentation used in the three month monitoring study conducted earlier at receptor R1.

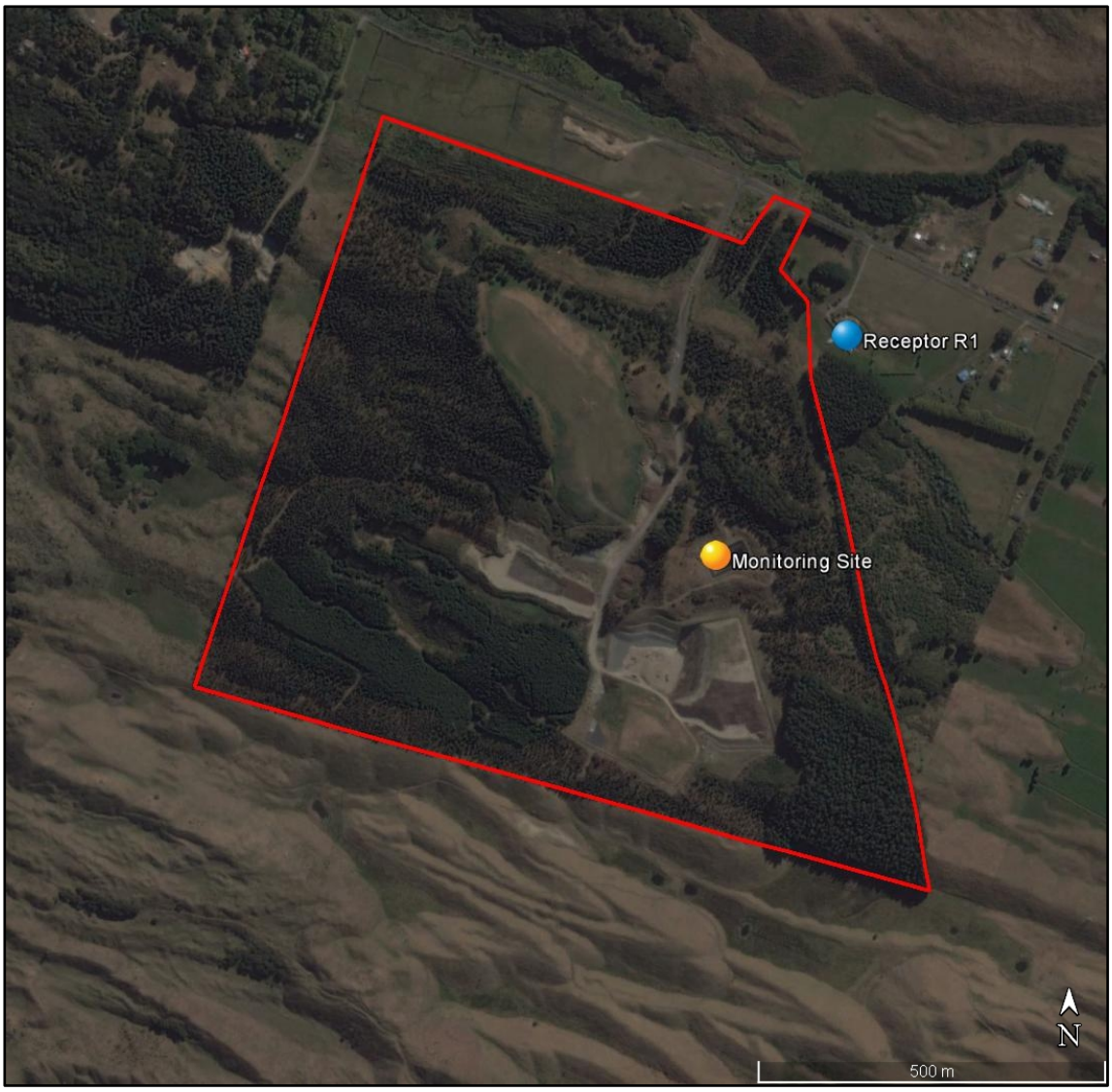

Figure 1: Monitoring Site Location

The response and performance of the analyser was checked under routine servicing by AirQuality, during which calibration gas was introduced into the sampling manifold to the requirements of AS 3580.4.1-2008.[1] The analyser was also periodically checked for zero-drift by introducing purified air into the sampling manifold and checking the values. Data were streamed to a website in real-time for continuous performance monitoring.

During post-processing of the data, AirQuality compared the values against the manufacturer's specifications, with adjustments being made to the data in accordance with AS 3580.4.1-2008, as required.

[1] AS 3580.4.1-2008. Methods of sampling and analysis of ambient air - Determination of sulfur dioxide - Direct reading instrumental method. Standards Australia, 12 June 20083.

2 Assessment Criteria

The New Zealand Ambient Air Quality Guideline (AAQG) for H_2S is 7 micrograms per cubic metre (µg/m^3) as a 1-hour mean (MfE, 2002), which equates to approximately 5 parts per billion by volume (ppb) at 20 °C.[2] Unlike the other health-based AAQGs (e.g. carbon monoxide, nitrogen dioxide, lead), the value for H_2S is based on preventing odour annoyance (or odour nuisance) and the resulting impacts on "well-being" (or amenity) rather than specific health effects. It is noted in MfE (2002) that the guideline value may not be suitable for geothermal areas, which is not applicable in the present study.

H_2S is a colourless gas with a distinctive odour at low concentrations. Humans detect the compound at concentrations of between 0.2 µg/m^3 and 2.0 µg/m^3, depending on its purity, and this is known as the odour detection threshold (ODT), which is defined as the concentration at which 50% of a group of people can detect an odour (MfE, 2002). According to MfE (2002), H_2S smells like rotten eggs at "about three to four times this concentration range", which equates[3] to a range of between 0.6 µg/m^3–0.8 µg/m^3 and 6 µg/m^3–8 µg/m^3. MfE (2002) also states that H_2S causes nuisance effects because of its unpleasant odour at concentrations well below those that cause health effects, and that continuous exposure to H_2S reduces sensitivity to this odour.

3 Results

The results of the continuous H_2S monitoring undertaken between 13 August and 11 September 2015 (inclusive) are summarised below. Due to an independent power outage event, the instrument did not operate between 10:52 pm on 31 August and 8:15 am on 2 September 2015 (i.e. 2,004 minutes or 33.4 hours or 5% of the total data were lost). For the 1-minute mean H_2S data analysed in this study, the percent valid data achieved was excellent at 100%, while the percent data capture and percent data loss achieved were 95% and 5%, respectively. The results indicate that relatively high concentrations were measured at the leachate pond compared with the three month monitoring study conducted earlier at receptor R1, which was to be expected given its closer proximity to the landfill's H_2S emission sources.

The results of the continuous ambient air quality monitoring are summarised in **Table 1** for the period between 13 August and 11 September 2015. The maximum 1-minute mean, 1-hour mean and 24-hour mean H_2S concentrations measured were 609 ppb, 235 ppb and 68 ppb, respectively. The 1-month mean H_2S concentration was 14 ppb.

Table 1: Ambient H_2S Concentrations for 13 August to 11 September 2015

Averaging Period	H_2S Concentration (ppb)
1-minute minimum	-0.8
1-minute maximum	609
25th percentile	0.4
50th percentile	0.8
75th percentile	2.1
95th percentile	98.8
1-hour minimum	-0.3
1-hour maximum	235
25th percentile	0.5
50th percentile	0.9
75th percentile	3.0
95th percentile	104
24-hour maximum	67.7

[2] At an ambient pressure of 1 atmosphere and a temperature of 20°C, 1 ppb of H_2S equates to 1.42 µg/m^3 (or 1 µg/m^3 = 0.71 ppb).
[3] This equates to an approximate H_2S concentration range of between 0.4 ppb–0.6 ppb and 4.3 ppb–5.7 ppb at 20 °C.

The 1-hour mean wind speed and wind direction frequency for the 1-month monitoring period are shown as a wind rose in **Figure 2**. The figure indicates that the predominant wind directions measured at the site were from the NW, SSE and SE[4], which indicates that there was a relatively high frequency of winds that blew from the leachate pond towards the monitoring site (i.e. winds from the SE and SW wind rose quadrants).

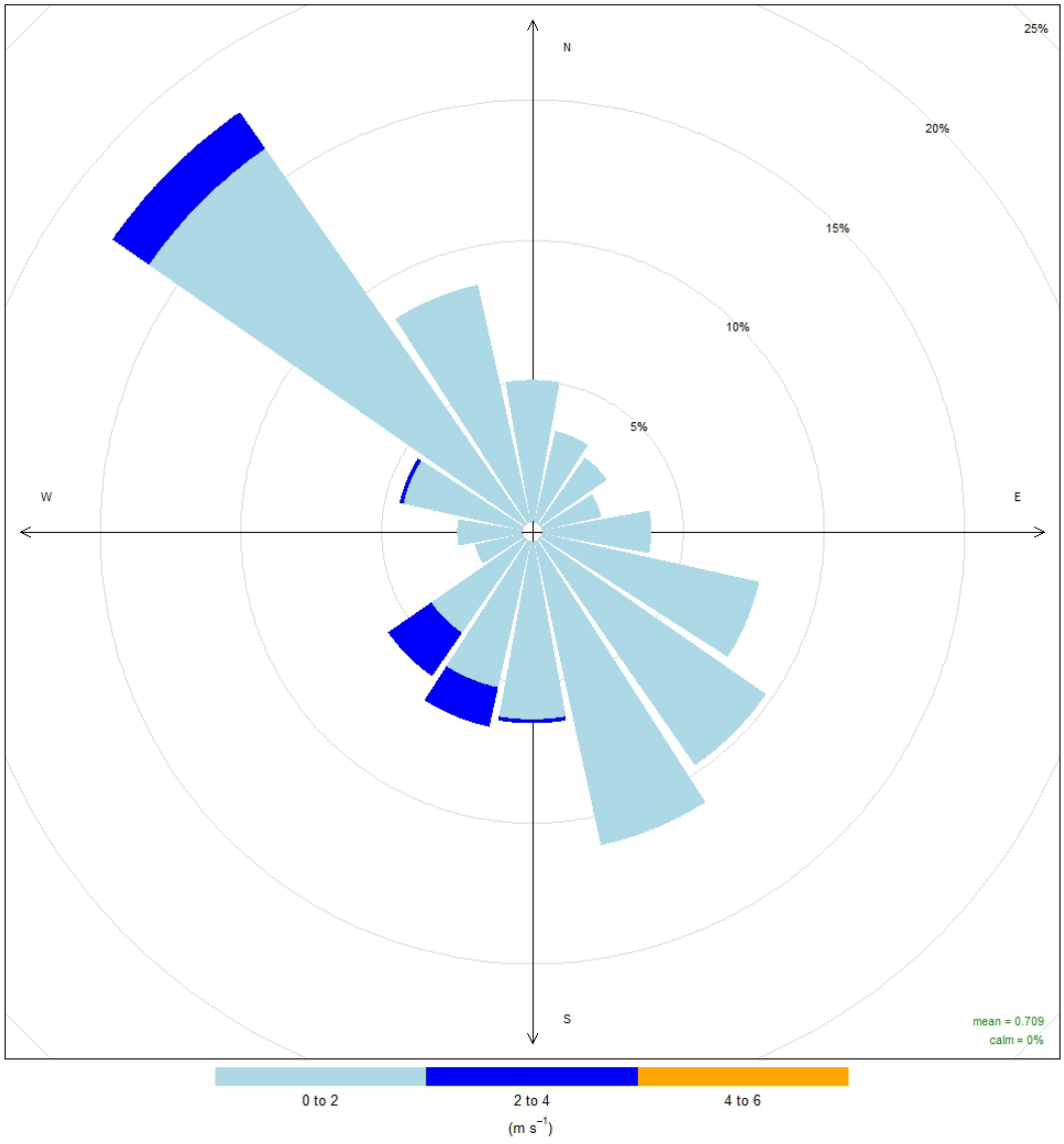

Figure 2: Wind Rose Showing 1-hour Mean Wind Speed and Direction

The 1-hour mean wind speed and wind direction frequency distribution is shown as a histogram in **Figure 3**. The figure indicates that the majority of the wind speeds were calm (less than 0.5 m/s) at 51%, with the remainder comprising of predominantly light wind conditions of between 0.5 m/s to 1.5 m/s (38%) and 1.5 m/s to 3.0 m/s (11%). Moderate wind conditions of between 3.0 m/s and 5.5 m/s only occurred 1% of

[4] NW (north-west), SSE (south-south-east) and SE (south-east).

the time and there were no wind speeds above 5.5 m/s. This indicates that worst-case conditions for pollutant dispersion were present during the monitoring period.

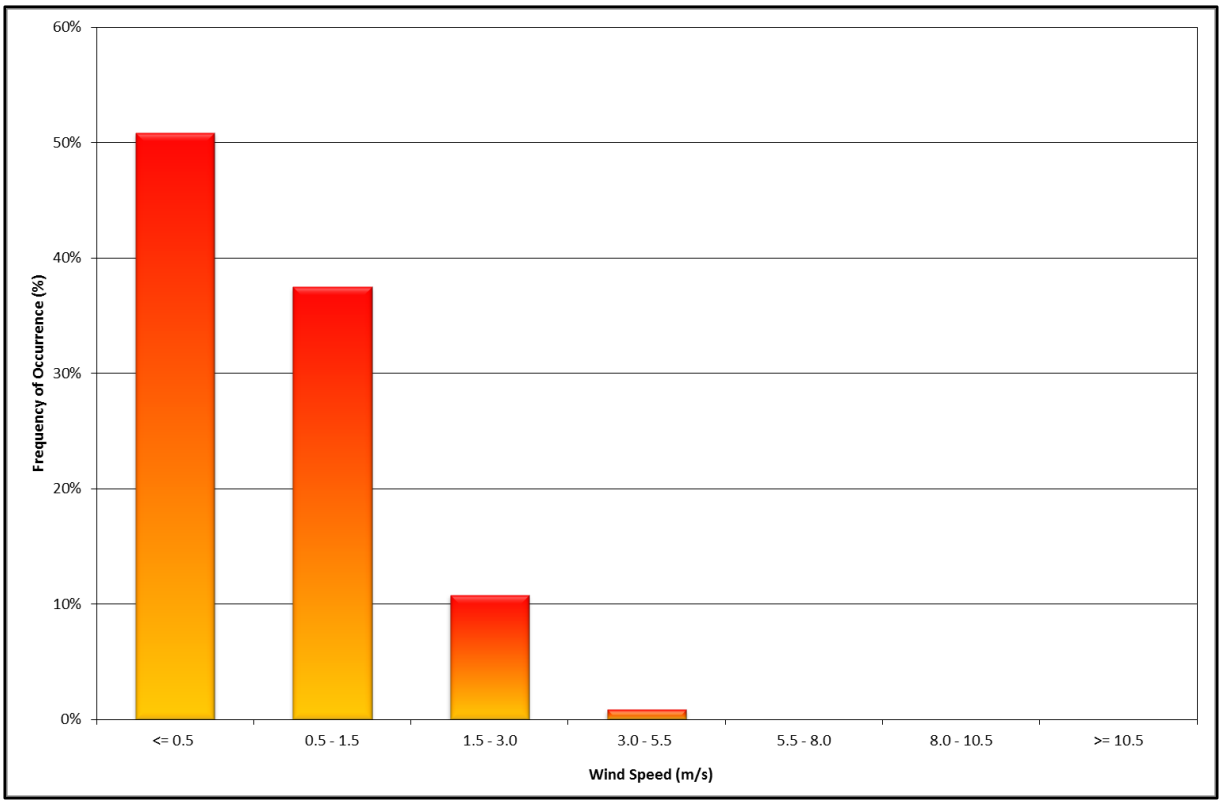

Figure 3: Wind Speed Frequency Distribution

The 1-hour mean H_2S concentration frequency distribution is shown as a histogram in **Figure 4**. Exceedances of the 1-hour mean AAQG for H_2S of 5 ppb were measured on 133 separate occasions, which represents 20% of the total 1-hour periods (662 hours). The majority of the exceedances occurred during the following wind directions:

- SSE 32%;
- S 16%;
- SSW 12%
- SE 12%;
- E 6%;
- ESE 6%; and,
- SW 5%.

It is highly likely that the source of the H_2S measured at the time of the exceedances was the leachate pond (or other sources onsite), given the fact that the monitoring location was situated downwind of the pond, which was being desludged at certain times during the monitoring period. Furthermore, the monitoring data indicate that the exceedances occurred during the evening or early morning and under calm to low wind conditions: the 1-hour mean wind speeds ranged between 0.1 m/s and 2.6 m/s, whilst 95% of the exceedances occurred between 5:00 pm and 7:00 am (inclusive).

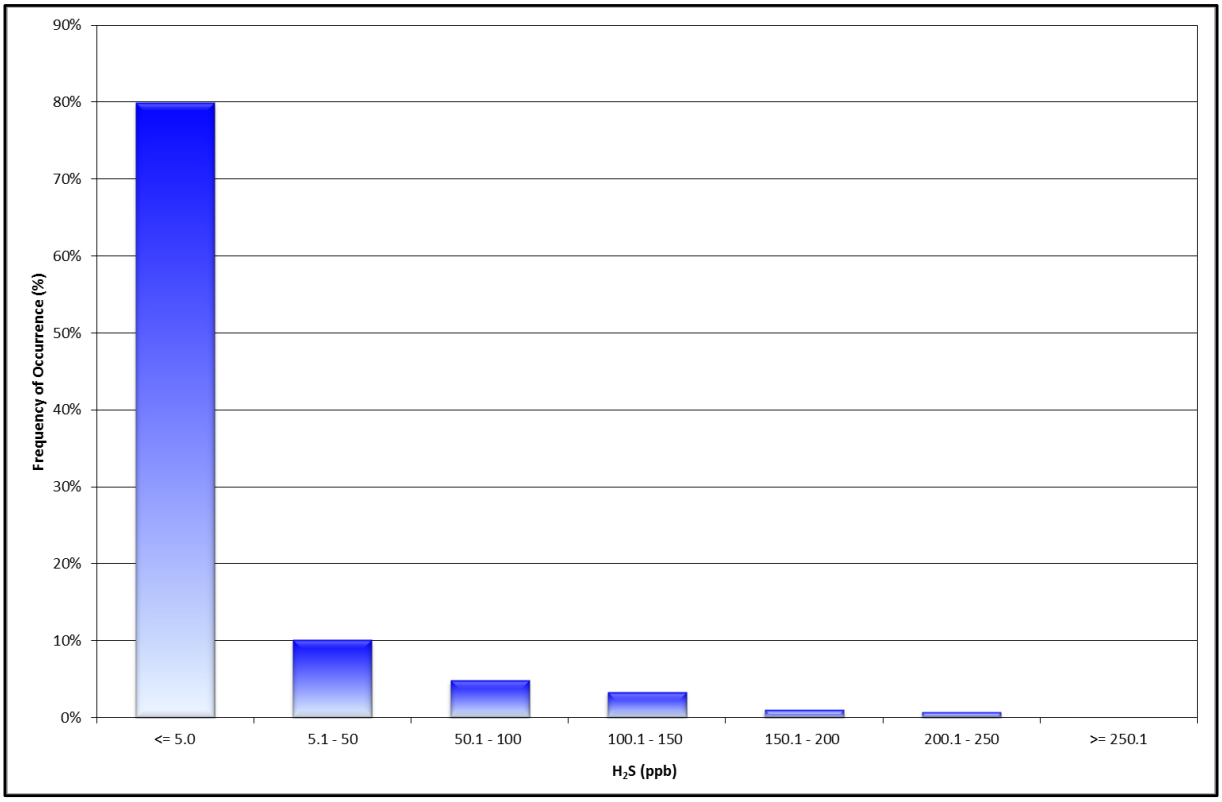

Figure 4: 1-hour Mean H_2S (ppb) Frequency Distribution

The top-10 exceedances of the 1-hour mean AAQG for H_2S are shown in **Table 2**.

Table 2: Top-10 Exceedances of the 1-hour Mean AAQG for H_2S

Date and Time	Wind Speed (m/s)	Wind Direction (degrees)	Wind Direction (compass point)[5]	1-hour Mean H_2S Concentration (ppb)
16/08/2015 7:00	0.2	178	S	235
7/09/2015 4:00	0.2	157	SSE	231
7/09/2015 6:00	0.3	160	SSE	231
7/09/2015 2:00	0.2	141	SE	204
22/08/2015 4:00	0.2	158	SSE	202
7/09/2015 3:00	0.2	177	S	199
28/08/2015 22:00	0.2	161	SSE	198
22/08/2015 5:00	0.3	162	SSE	186
23/08/2015 22:00	0.3	172	S	186
7/09/2015 1:00	0.2	157	SSE	185

Time-series plots of the 1-minute mean and 1-hour mean H_2S concentrations are shown in **Figure 5(a)** and **Figure 5(b)**, respectively. The 1-hour time-series plot shown in **Figure 5(b)** and the 1-month mean H_2S concentration of 14 ppb indicate that there were a significant number of 1-hour periods above the 1-hour mean AAQG of 5 ppb.

Time-series plots of the 1-hour mean data for H_2S concentration (ppb), wind speed (m/s), wind direction (degrees), atmospheric pressure (hPa) and air temperature (°C), are shown in **Figure 6**.

[5] N (North), NNE(North-North-East), NE(North-East), ENE (East-North-East), E (East), ESE (East-South-East), SE (South-East), SSE (South-South-East), S (South), SSW (South-South-West), SW (South-West), WSW (West-South-West), W (West), WNW (West-North-West), NW (North-West), and NNW (North-North-West).

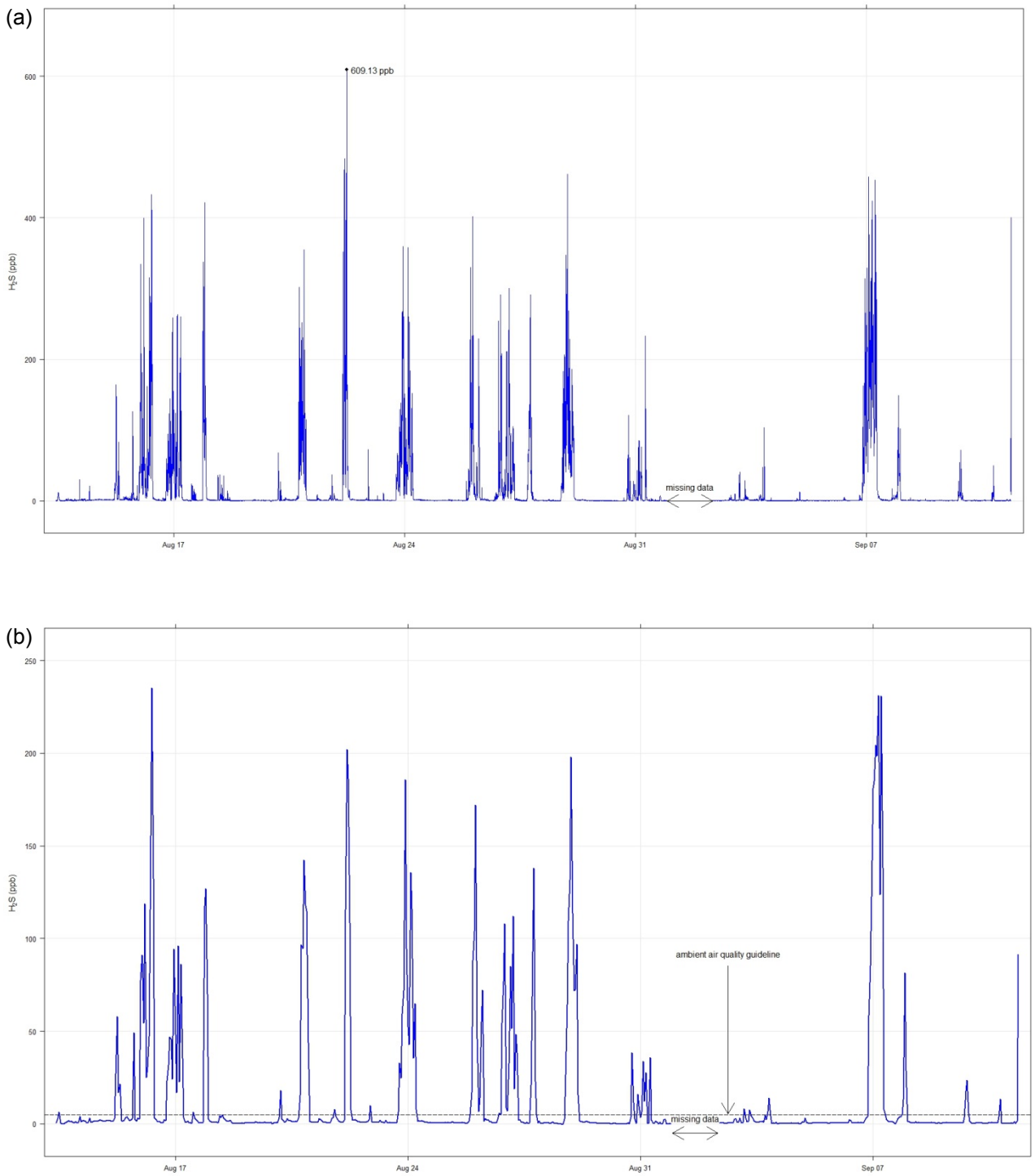

Figure 5: Time-series Plots for (a) 1-minute Mean H_2S (ppb) and (b) 1-hour Mean H_2S (ppb)

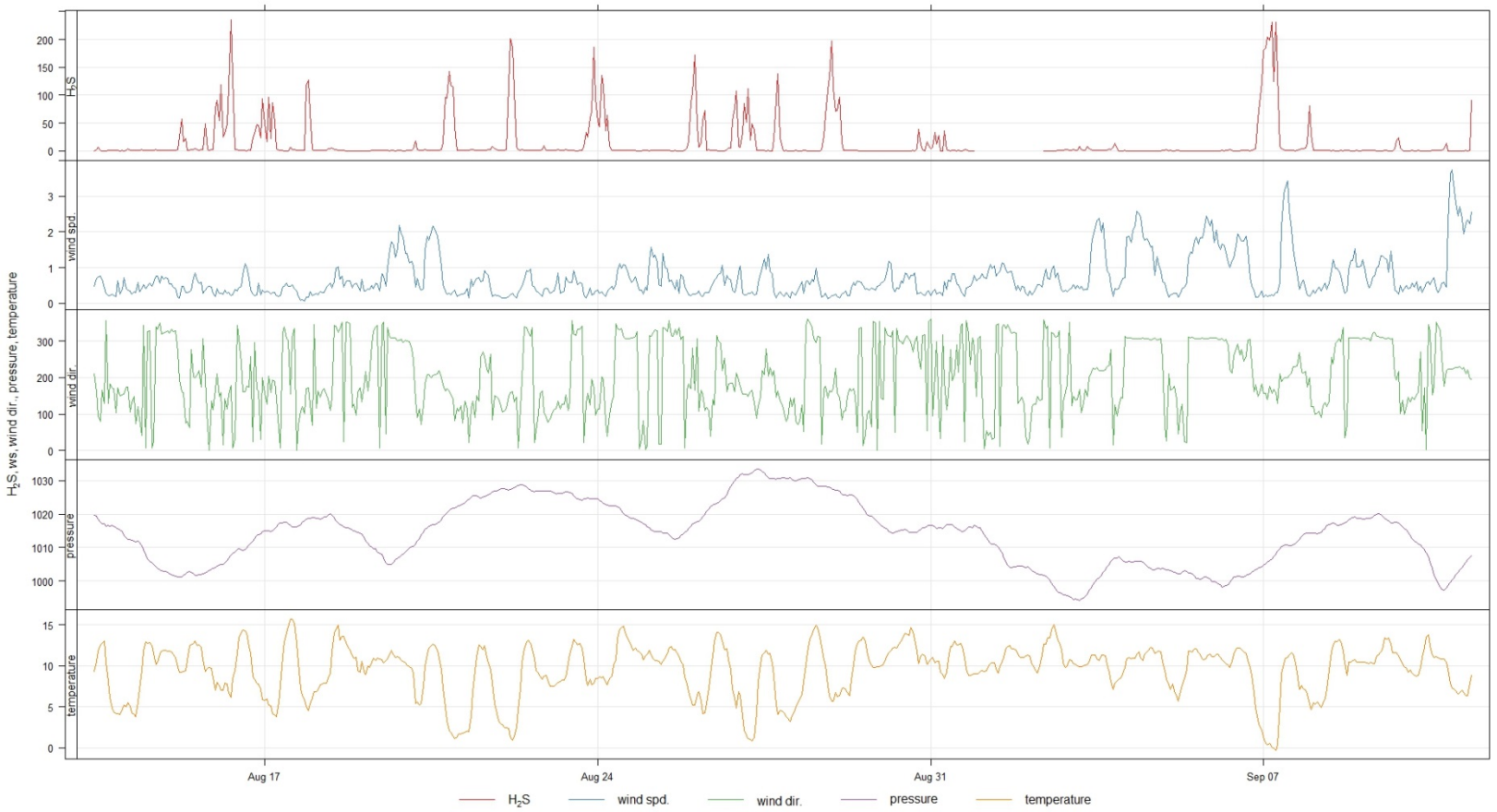

Figure 6: Time-series Plots for 1-hour Mean H_2S (ppb), Wind Speed, Wind Direction, Atmospheric Pressure and Air Temperature (top to bottom)

Figure 7 shows the 1-hour mean concentrations of H_2S measured at the site as a pollution rose, i.e. it presents the same data as per the wind rose shown in **Figure 2**, however, the wind speed data were substituted for the H_2S concentration data.

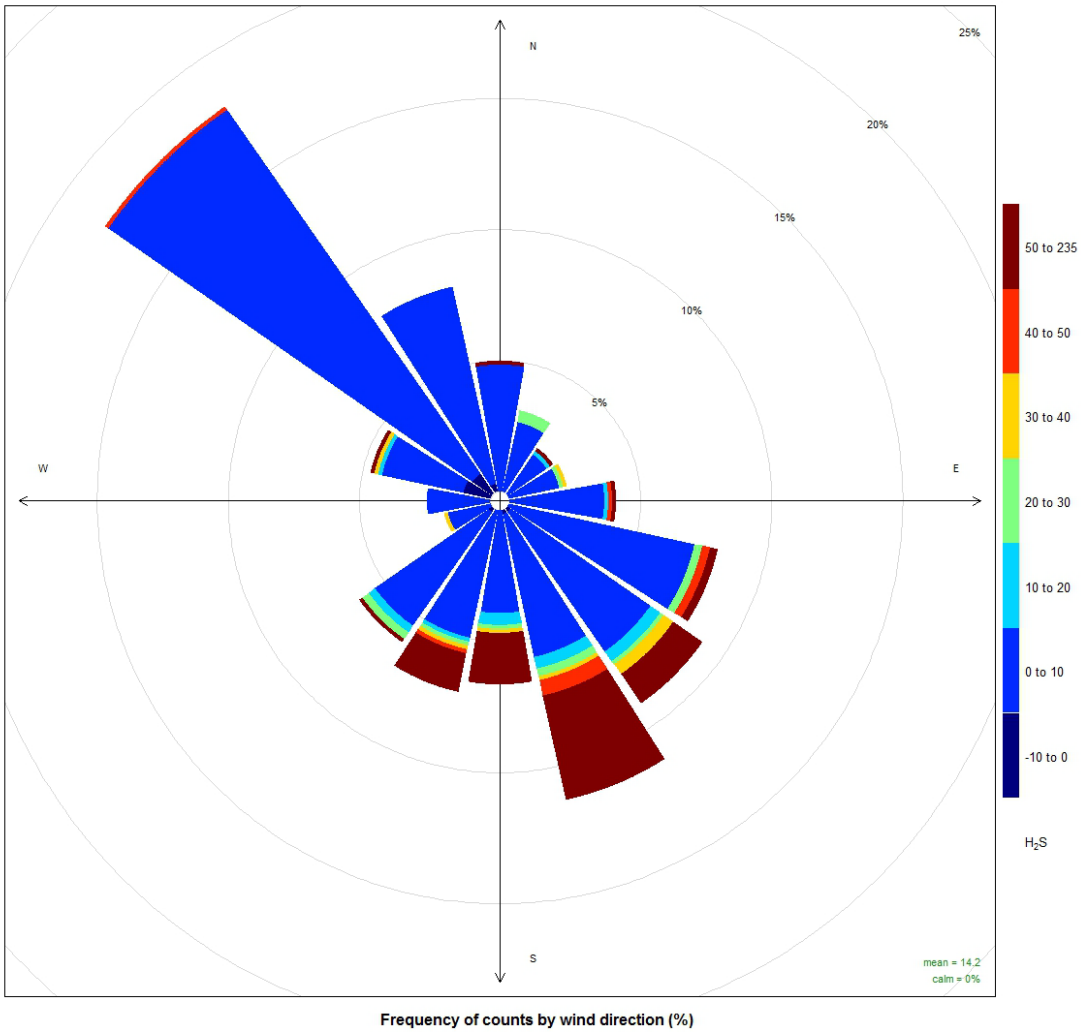

Figure 7: Pollution Rose for 1-hour Mean H_2S (ppb) and Wind Direction

The figure indicates that the highest H_2S concentrations were measured during winds blowing from the ESE, SE, SSE, S, SSW and SW. In other words, based on the data for the period, the figure indicates that the desludging of the pond (not to exclude other potential emissions sources at the landfill, such as the working face, leachate collection manhole and stage 2 emission hotspots) are likely to have contributed to the concentrations measured at the monitoring location.

Figure 8 shows the 1-hour mean concentrations of H_2S measured at the site as a polar plot, or a bivariate plot of concentrations varying by wind speed and wind direction.

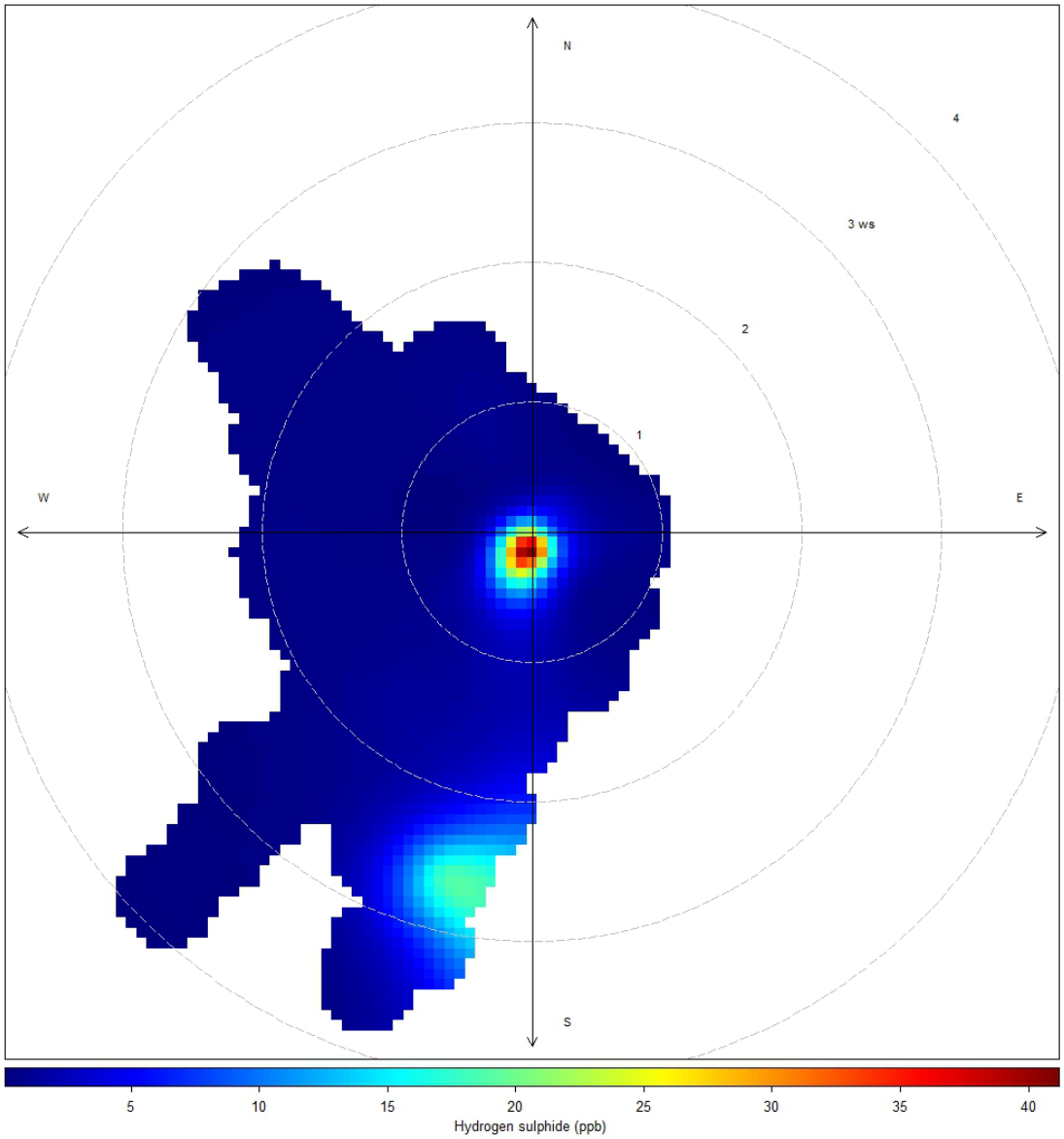

Figure 8: Polar Plot for 1-hour Mean H_2S (ppb), Wind Speed and Wind Direction

The figure shows the H_2S concentrations in polar coordinates by both 1-hour mean wind speed and wind direction. Mean concentrations were calculated for wind speed-direction 'bins' (e.g. wind speeds of 0–1, 1–2 m/s, and wind directions of 0–22.5, 22.5–45 degrees etc.). The figure further corroborates the suggestion that the highest concentrations were measured during low wind speeds (<1 m/s) originating from the SE and SW quadrants. The figure also indicates that high concentrations of H_2S were also measured during wind speeds of between 2 m/s and 3 m/s originating from the SSW; and that the emission sources may well have been the working face or stage 2 emission hotspots.

Figure 9 shows a scatter plot of the 1-hour mean concentrations of H_2S measured at the site (y-axis) against wind speed (x-axis) using 'hexagonal binning', during which the data is 'binned' and different colours are applied to the intervals by the number of counts of occurrences in each bin. Hexagonal binning is particularly effective because of the way hexagons can be placed next to one another and, as with traditional scatter plots, prevents the data points plotting over each other which in large data sets often leads to difficulties in interpreting what the underlying relationship looks like. The figure indicates that the highest H_2S concentrations typically occurred during low wind speed conditions.

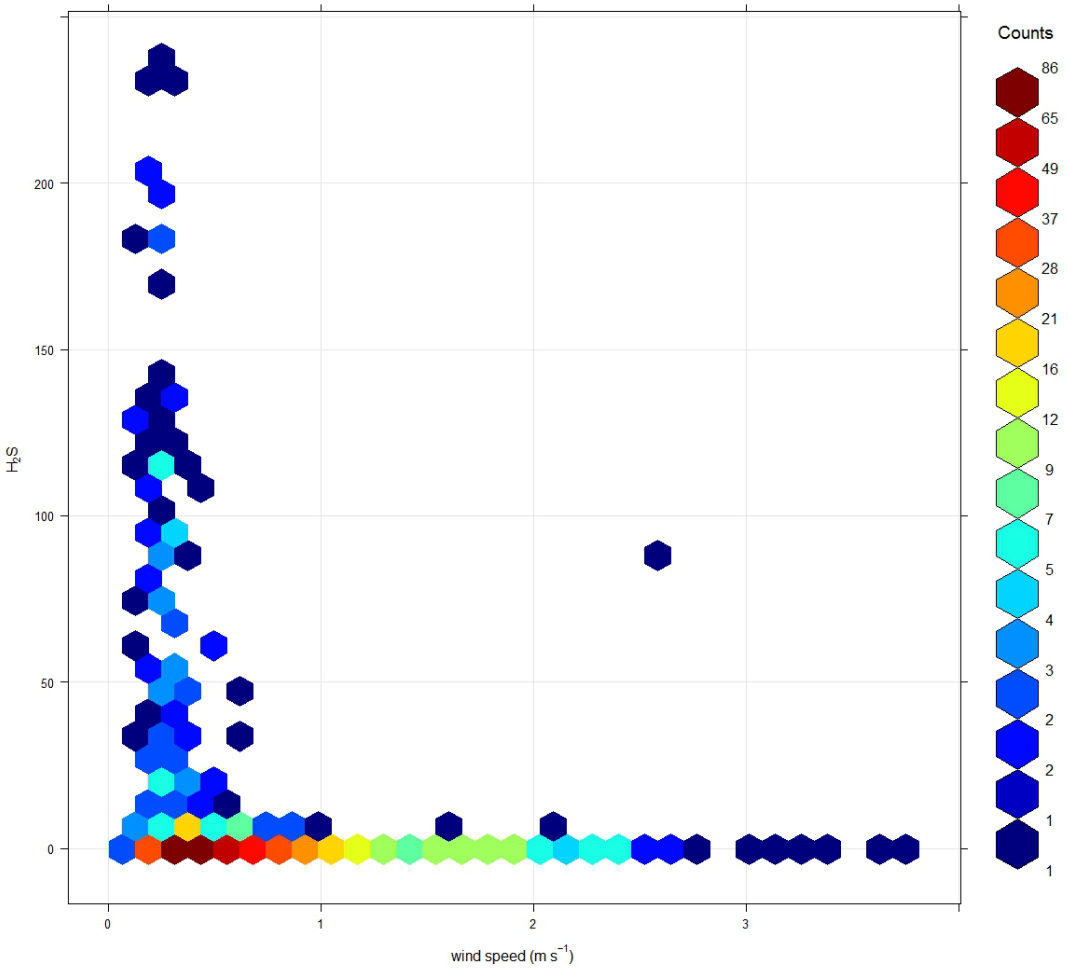

Figure 9: Scatter Plot for 1-hour Mean H_2S (ppb) Against Wind Speed Using Hexagonal Binning

Figure 10 shows a scatter plot of the 1-hour mean concentrations of H_2S measured at the site (y-axis) against wind speed (x-axis) using a kernel density estimate to show where most points lie. The 'intensity' is a measure of how many points lie in a unit area of wind speed and H_2S concentration. Again, the figure indicates that the highest H_2S concentrations typically occurred during low wind speed conditions.

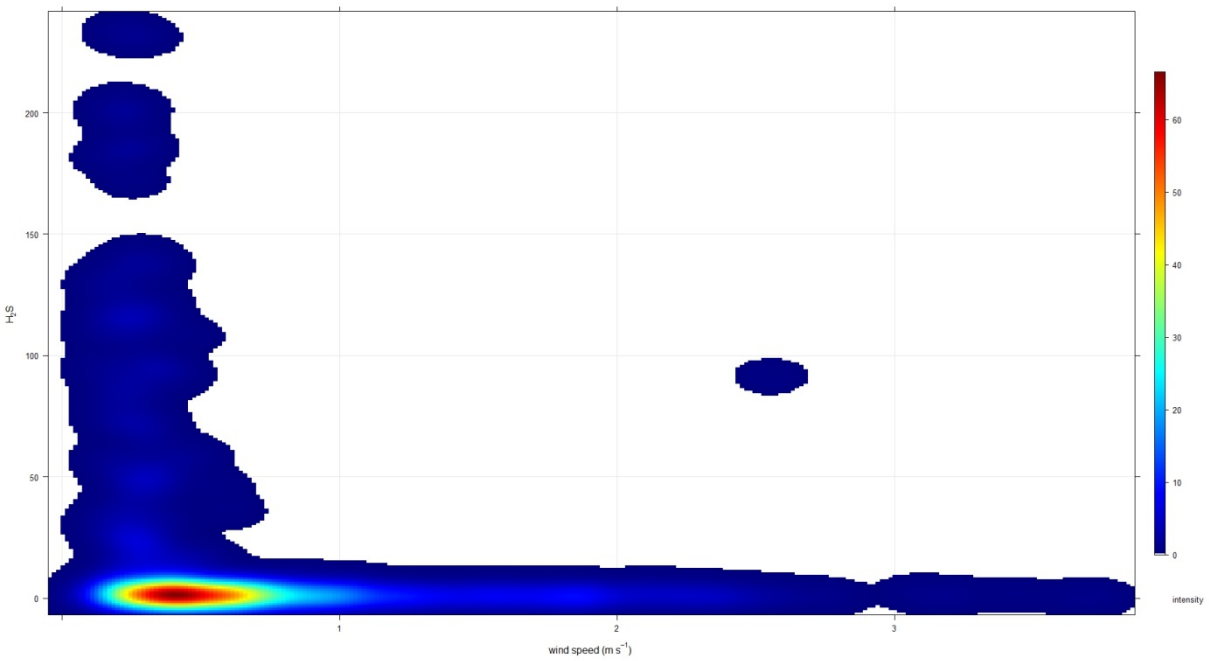

Figure 10: Polar Plot for 1-hour Mean H_2S (ppb) Against Wind Speed Using Kernal Density

Figure 11 shows the 1-hour mean concentrations of H_2S measured at the site as a percentile rose, or percentile concentrations of H_2S varying by 10 degree wind direction segments. The figure shows the distribution of H_2S concentrations by wind direction, conditioned on time of day i.e. day-time (left) and night-time (right). The figure further corroborates the suggestion that the highest concentrations were measured during the night-time and under winds originating from the SE and SW quadrants.

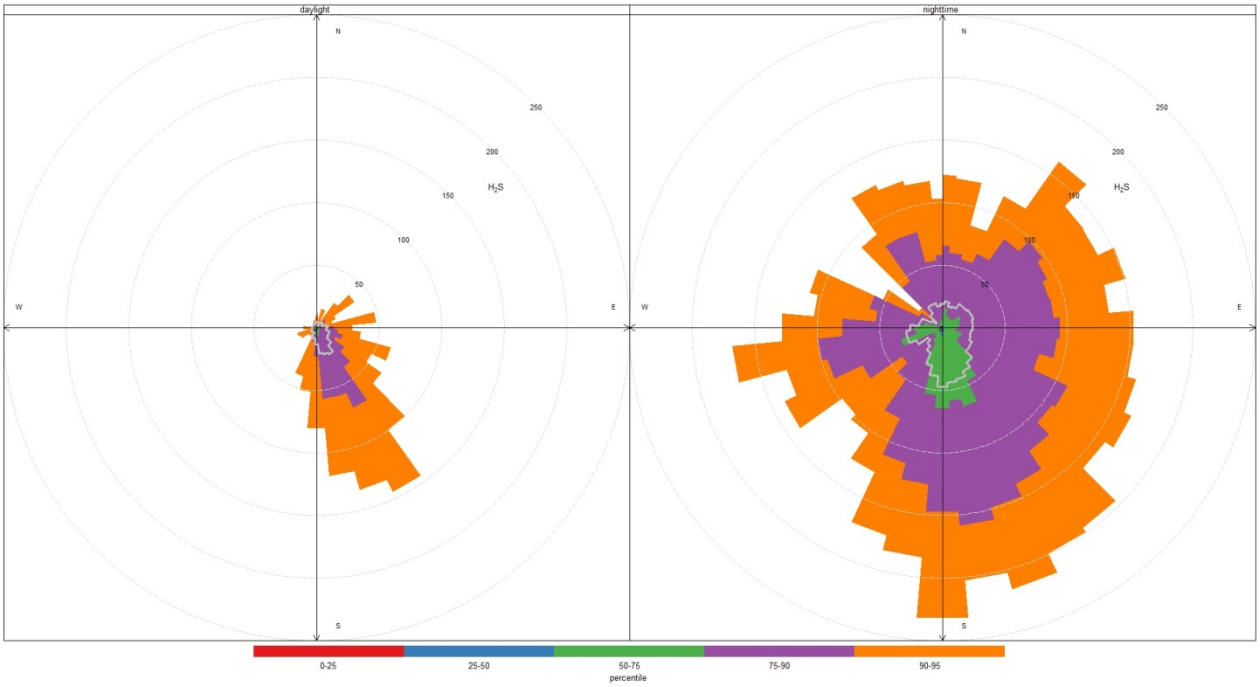

Figure 11: Percentile Plot for 1-hour Mean H_2S (ppb) and Wind Direction for Day- and Night-time

Figure 12 shows the 24-hour (daily) mean concentrations of H_2S measured at the site as a calendar plot i.e. in a conventional calendar format with the main purpose being to help visualise potentially complex data in a familiar way. **Figure 12(a)** shows the 24-hour mean concentrations of H_2S (in ppb) measured each day between 13 August and 11 September 2015 against a colour scale (magnitude), while **Figure 12(b)** shows the 24-hour mean wind vectors based on the daily mean wind speed and direction data and **Figure 12(c)** shows the 24-hour mean values. For example, the highest 24-hour mean H_2S concentration of 68 ppb was measured on Monday 7 September 2015 during which light winds (1 m/s) blew from the SSW. Incidentally, the maximum 24-hour mean H_2S concentration of 68 ppb was below the World Health Organization's 24-hour mean ambient air quality (health-based) guideline for H_2S of 150 µg/m^3 (106 ppb).[6]

[6] Air Quality Guidelines for Europe, Second Edition, World Health Organization (WHO) Regional Office for Europe, Copenhagen, European Series, Number 91, 2000.

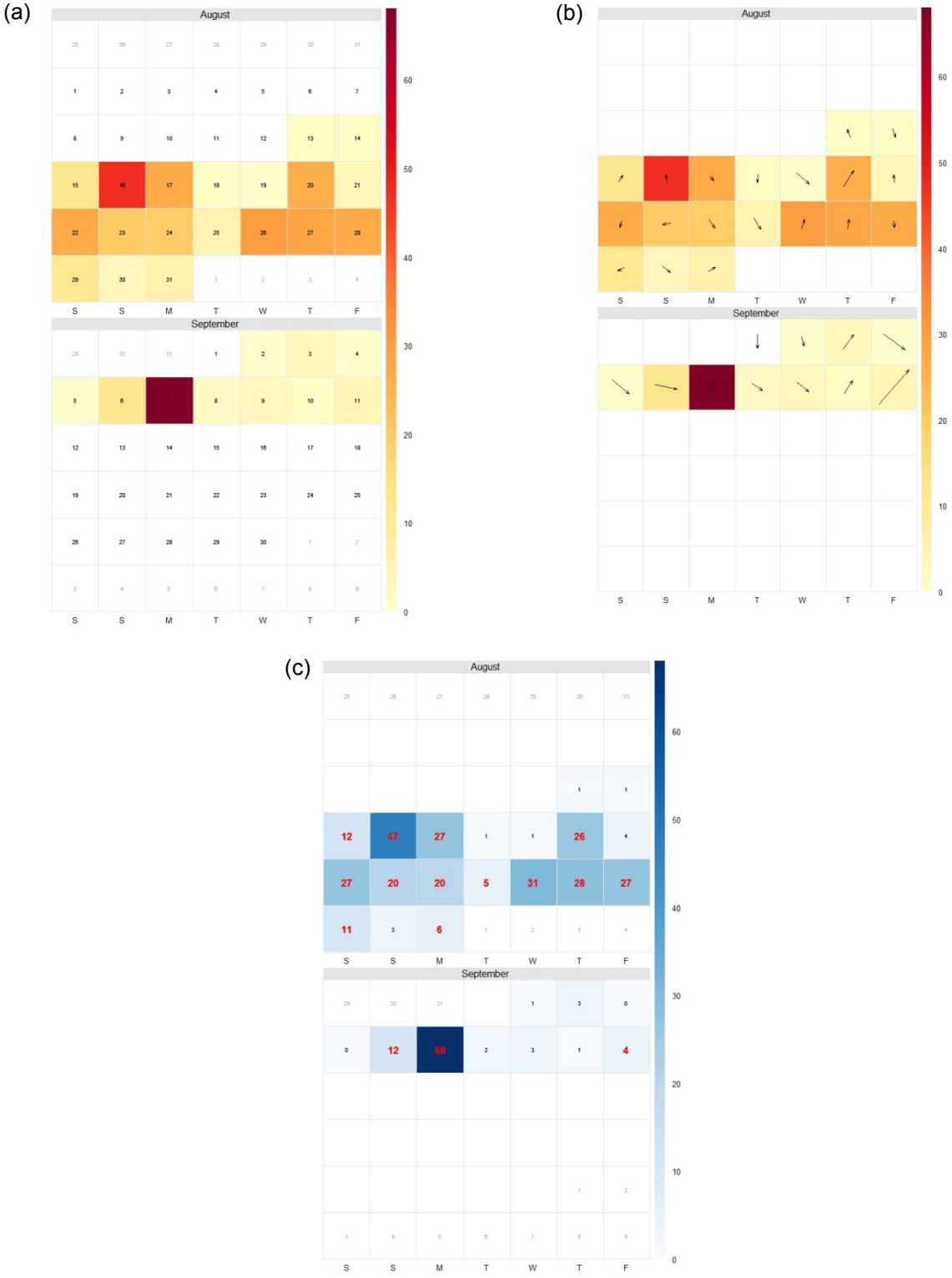

Figure 12: Calendar Plot for 24-hour Mean H_2S (ppb) for (a) Daily, (b) Wind Vectors and (c) Values

4 Discussion

The results for the 1-month monitoring period between August and September 2015 indicate that:

a) The concentrations of H_2S measured at the monitoring site were relatively high. There were 133 exceedances of the 1-hour mean AAQG for H_2S of 5 ppb during winds from the SE and SW quadrants;
b) Emission sources of H_2S (e.g. leachate pond, leachate collection manhole, working face and stage 2 emission hotspots) are likely to have contributed to the concentrations measured at the monitoring site;
c) The concentrations of H_2S measured at the monitoring site did not exceed the relevant Workplace Exposure Standards for H_2S such as the 8-hour mean Time-Weighted Average (TWA), or the 15-minute mean Short Term Exposure Limit (STEL).[7]

The US EPA screening model, SCREEN3 Version 96043, was used to assess the potential odour impact at sensitive receptor R1, using the maximum 1-hour mean H_2S concentration measured at the leachate pond of 235 ppb (337 µg/m^3) to back-calculate the emission rate for the leachate pond (ground-level area source with a dimension of 25 m by 50 m). The model determined that under worst-case meteorological conditions (stable atmosphere or 'stability class F' with a wind speed of 1 m/s at 10 m, which equates to 0.3 m/s at a height of 1 m based on a log-law vertical wind speed profile), the 1-hour mean H_2S concentration at a distance of 5 m from the leachate pond equalled the measured concentration of 337 µg/m^3 (the emission rate was 4.72 x 10^{-6} g/s/m^2)[8]. At a distance of 360 m from the leachate pond (i.e. at receptor R1), the H_2S concentration was predicted to be 19 µg/m^3. The mass concentrations of H_2S measured at the monitoring location (337 µg/m^3) and predicted by the model at receptor R1 (19 µg/m^3) were converted into odour concentrations (odour units per cubic metre or OU/m^3) by dividing the mass concentration by the odour detection threshold (ODT), which in this assessment was assumed to be 0.67 µg/m^3 (0.47 ppb). Thus, the maximum 1-hour odour concentrations at the monitoring site and at receptor R1 are estimated to be 503 OU/m^3 and 28 OU/m^3, respectively.[9]

Based on the results of the screening-level model and the ambient monitoring presented above, MWH considers that the potential for odour nuisance complaints at 645 Hōkio Beach Road (receptor R1) during the period of the desludging was *high*. Whilst no complaints were received by HDC during the period of the desludging (it is noted that the owners of the property at 645 Hōkio Beach Road were overseas at the time), this conclusion is a *conservative estimate* of the potential impact, based on the screening-level model and ambient monitoring results.

MWH's report dated February 2015 contained a number of odour mitigation measures for the landfill, including measures to control odour at the leachate pond. These measures included, but were not limited to, reducing the residence time of the leachate held in the pond, avoiding certain meteorological conditions for planned maintenance (desludging) and using mechanical aeration, if required under low DO conditions[10].

Analysis of the 1-hour mean H_2S concentrations measured for the 13-hour period between 9:00 pm on 6 September to 9:00 am on 7 September 2015 (inclusive) indicates that the concentrations were above the 1-hour mean AAQG for the entire time and increased from an initial concentration of 58 ppb to a peak concentration of 231 ppb at 4:00 am the following day. The wind speeds during this period were low (<0.3 m/s) and blowing from the SSE and S. The data for this period also indicate that there was a strong, negative correlation (r^2 = 0.7435; Pearson's product-moment correlation coefficient, r, = -0.86) between air temperature and H_2S concentration, which suggests that the ambient concentrations decreased as the air temperature increased. Atmospheric pressure increased from an initial pressure of 1,004 hPa at 9:00 pm

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7 Ministry of Business, Innovation and Employment, 2013. Workplace Exposure Standards and Biological Exposure Indices, 7th Edition, February 2013.

8 The model was first run using a unitary emission rate (i.e. 1 g/s/m^2) to determine the concentration at the monitoring location. The emission rate of 4.72 x 10^{-6} g/s/m^2 was calculated according to the formula: 1/(predicted concentration/measured concentration). The model was then re-run with the estimated emission rate of 4.72 x 10^{-6} g/s/m^2 to predict the 1-hour mean concentrations at the monitoring location and at receptor R1.

9 MfE (2003) recommends an odour assessment guideline for dispersion modelling of 2 OU/m^3 as a 99.9 percentile 1-hour mean.

10 'DO' is an abbreviation for 'dissolved oxygen'.

on 6 September to 1,010 hPa at 9:00 am on 7 September 2015. This suggests that stable atmospheric conditions, calm to low wind speeds and low air temperatures occurred, which are typical of katabatic winds (cold air drainage winds and temperature inversions which generally occur during winter and early spring), and which are likely to have limited the dispersion of H_2S (and odour) at the landfill during this period, causing an elevation in the measured ambient H_2S concentrations. The elevated concentrations measured on 6 and 7 September and also on 9 and 10 September and 31 August, are interesting as the desludging work was completed by Friday 28 August. In other words, these elevated concentrations were not associated with the desludging activity itself (nor perhaps were they associated with fugitive H_2S emissions from the leachate pond), but rather they may have been caused by fugitive emissions of H_2S from the working face, leachate collection manhole and/or the stage 2 emission hotspots.

As the findings of this report indicate that, based on the results of the screening model and ambient monitoring for H_2S, the potential for odour effects (e.g. nuisance complaints) beyond the site boundary still remains, MWH recommends that the odour mitigation measures stated in its report dated February 2015 for the working face, leachate collection manhole and stage 2 are implemented without further delay. These measures include, but are not limited to:

- Controlling odour at the working face (e.g. keeping an adequate supply of daily cover onsite, the deep and prompt burial of malodourous waste, regularly inspecting cover integrity);
- Applying effective capping (e.g. clay layer) across stage 2; and,
- Controlling odour and landfill gas emissions at the leachate collection manhole (e.g. by biofiltration).

5 References

Carslaw, D.C. and K. Ropkins, (2012). openair — an R package for air quality data analysis. *Environ. Model. Softw*., Vol 27–28, 52–61.

MfE, (2002). Ambient Air Quality Guidelines, Ministry for the Environment (MfE) and Ministry of Health (MoH), Air Quality Report No 32, May 2002.

MfE, (2003). Good practice guide for assessing and managing odour in New Zealand, Ministry for the Environment (MfE), June 2003.

6 Closure

I trust that this meets your requirements. Should you require any additional information or clarification, please do not hesitate to contact me on (09) 580 4575 or 021 766 576.

Yours sincerely

Dr Doug Boddy
Senior Air Quality Consultant
MWH New Zealand Limited

Reviewed By:

Dr Paul Heveldt
National Environmental Science Specialist
MWH New Zealand Limited

Copy to: Phil Landmark and Roger Hulme