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Electronic Nose Equivalence to Odour Units

Validation Study

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Executive Summary

Meat and Livestock Australia (MLA) commissioned The Odour Unit Pty Limited (TOU) to undertake a study to assess the degree to which an equivalence relationship can be formulated between an Electronic Nose (E-Nose), manufactured by E-Nose Pty Limited, and measurements of odour concentration by dynamic olfactometry. This project focused on preparing and analysing a large number of synthetic rendering mixture and actual samples from the meat industry using both the E-Nose and dynamic olfactometry testing. TOU developed a methodology to test a range of odour concentrations from tens to thousands of odour units to give a representation of odours that may be experienced indoors or under downwind ambient conditions. The aim was to determine the validity of converting E-nose readings from five individual sensors into odour concentration readings based on their correlation (millivolts vs odour units).

The findings of study are as follows:

- There was evidence of a positive log-linear relationship between odour concentration derived from both dynamic olfactometry and E-Nose testing, beyond the lowest detection limit of the E-Nose;
- The millivolt readings for each of the five sensors had independent relationships and gradients versus odour concentration, suggesting that they are responding to different groups of odorant compounds;
- Four out of five sensors had no significant response until the odour concentration of the synthetic rendering mixture exceeded (i.e. lowest detection limits) 200 to 400 ou on the default sensitivity setting;
- One sensor detected the entire range of synthetic rendering mixture odour concentrations that were presented (50 ou to 9,740 ou) on both the default sensitivity setting and highest sensitivity setting;
- The change of sensitivity of sensors to the highest setting did not improve lowest detection limits;
- The highest sensitivity setting did increase sensitivity (i.e. the gradient of the ou/mV relationship) for the sensors once the lowest detection thresholds were exceeded;
- There appeared to be a positive relationship between actual meat industry sample odour concentration derived from both dynamic olfactometry and E-Nose testing however the exact correlation was less conclusive;
- There was no significant response from any of the five sensors until the meat industry odour concentrations exceed the lower detection limit that ranged from 300 ou to 2,000 ou, depending on the individual sensor;
- Overall, the E-Nose did not detect the actual meat industry sample odours as well as it did for the synthetic rendering mixture;
- The E-nose instrument was not able to quantitatively differentiate between different odour characters, given the limited way in which the sensor results are expressed as five individual millivolt readings. There appear to be qualitative differences but such a differentiation would be difficult for a typical meat industry user to determine.

Based on the experience in the operation of the E-Nose instrument and the above findings, the following conclusions were made:

- There is validity and potential in the converting of E-Nose millivolt readings to dynamic olfactometry odour unit measurements based on their correlation;

- The E-Nose does not appear to be capable of detecting the synthetic or the industry odour at the required low downwind ambient concentration levels, even at the highest sensitivity settings. The use of the E-Nose at the gate/boundary fence line in order to alert the user of upset odour events in real-time may not be a realistic expectation.

- The E-Nose in its current configuration would be most suited to being installed to monitor at or near the industry emission sources, where higher odour concentration levels are likely;

- The E-Nose appears to have the ability to detect small changes in odour concentrations when operating beyond the sensors' lower detection limits, a feature beyond the capability of conventional odour sampling and dynamic olfactometry testing;

- The E-Nose sensors were not suitable for detecting the particular meat industry rendering plant odour presented to it during this study.

Based in the above conclusions the following recommendations are put forward for consideration:

- Software should be developed to combine the five unique sensor points into one point and relate that back to odour concentration and perhaps odour character. An outcome of this would be a more simplified interpretation of the odour concentration readings.

- Recommend the use of the current E-nose instrument in the Meat and Livestock industry only at or near the odour emission source and not at the gate/boundary;

- Determine the odour upset alert level setting of the E-Nose (instrument to be installed at or near the sources) based on the use odour emission sampling, testing and dispersion modelling assessment, complemented by emission source-specific millivolt to odour unit correlation testing;

- Encourage E-Nose Pty Limited to refine the sensors to detect lower ambient level odour concentrations;

- For E-Nose instruments that are installed at or near the source there would be a need to establish the most optimal sensitivity setting of the instrument. Set correctly, the E-Nose has the potential to detect the more minor fluctuations in odour emission that are not easily or readily detected by conventional odour sampling and dynamic olfactometry;

- Further testing may be required to establish and confirm whether the finding that the E-Nose was unsuitable for detecting the industry rendering odours that were sampled at the industry site was an isolated occurrence or whether it truly represents all rendering odours across the whole industry. Furthermore, testing with other meat industry specific odours such as from abattoirs and intensive livestock feedlots would be useful data to obtain.

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1 Background

1.1 Introduction

On 30th May 2008, Meat and Livestock Australia (MLA) commissioned The Odour Unit Pty Limited (TOU) to undertake a study to assess the degree to which an equivalence relationship can be formulated between an Electronic Nose (E-Nose), manufactured by E-Nose Pty Limited, and measurements of odour concentration by dynamic olfactometry.

TOU's Managing Director, Terry Schulz, was Project Leader for the MRC RPDA.303 research project that had identified the potential for E-Nose technology. An outcome of that project was the recommendation for the development of a meat industry specific E-Nose instrument. It was suggested that a synthetic odorant mixture be developed and utilised as a reference gas for research purposes. E-Nose Pty Limited has developed a meat industry specific instrument over the last decade to the stage where MLA has requested for this equivalence relationship study to be undertaken.

This project focused on preparing and analysing a large number of synthetic and actual samples from the meat industry using both the E-Nose and dynamic olfactometry testing. TOU developed a methodology to test a range of odour concentrations from tens to thousands of odour units to give a representation of odours that may be experienced indoors or under downwind ambient conditions. The range was selected based on the expected use of the E-Nose, which would be within process buildings and/or at the gate/boundary fence line in order to alert the user of upset odour events in real-time. It was assumed that the E-nose would perform optimally at ambient level odour concentrations where dynamic olfactometry often falls short.

The aim was to determine the validity of converting E-nose readings into to odour concentration readings based on their correlation (millivolts vs odour units). This report documents the methodology, results and findings of this study.

2 Project Objective

2.1 Project Aim

The aim of the project is to determine whether a correlation exists between odour concentration derived from both dynamic olfactometry and E-Nose testing methodologies. A secondary objective is to assist in the acceptance of the E-Nose by regulatory authorities. Should the E-Nose instrument is found to be successful, it is expected to find application within the meat industry for 'real time' monitoring of ambient odours downwind of processing facilities.

3 Methodology

3.1 Odour Preparation/Sampling

3.1.1 Parent Synthetic Odour Sample Preparation

The synthetic sample preparation program carried out by Dr David Stone from Advanced Analytical Australia Pty Limited is provided in **Table 3.1**. A breakdown of the compounds utilised has been listed in **Appendix A**.

Table 3.1: Synthetic Sample Preparation Program

Parent Sample ID	Date Prepared
1S – Synthetic	16/06/08
2S – Synthetic	23/06/08
3S – Synthetic	30/06/08
4S – Synthetic	07/07/08

3.1.2 Parent Industry Odour Sample Collection

Foul air samples were collected weekly from A. J. Bush & Sons (Manufactures) Pty Ltd at their Riverstone rendering plant. Two major point source odours that were considered to be problematical of the industry were selected for sampling to be analysed by E-Nose and dynamic olfactometry. These were the cooking room foul air ('Stream A') that is currently being collected and treated by a biofilter, and the Cooker non-condensable gases line (Stream 'B') that was run into a boiler furnace.

The method used for collecting samples from the foul air streams involved drawing the sample gas through a Teflon™ sampling tube into a single use, Nalophan sample bag. The bag is housed within a container (sampling drum) that is evacuated with a vacuum pump, and the sample collected by induced flow. The "lung method", by which this sampling procedure is known, allows the sample air to be collected without coming into contact with any potentially odorous material.

It was found that Stream 'B' had an extremely high odour concentration that required pre-dilution sampling with a TOU in house SupaDiluta instrument. The SupaDiluta device consists of a stainless steel syringe with Teflon internals designed to extract a fixed volume of sample for each sampling stroke. Depending on the desired dilution ratio, a measured volume of sample is pumped into a bag pre-filled with dry nitrogen.

Foul air samples were transported to the TOU laboratory and stored out of direct sunlight/strong daylight and kept at a temperature of less than 25 ^{0}C to minimise sample degradation. These samples formed the role of the parent samples to be post-diluted in TOU's laboratory to a set of sub-samples with concentration ranges of tens to thousands of odour units.

The sample collection program is detailed in **Table 3.2**.

Table 3.2: Industry Sample Collection Program	
Parent Sample ID	**Date Collected**
5A – Stream 'A'	14/07/08
6A – Stream 'A'	21/07/08
6B – Stream 'B'	21/07/08
7B – Stream 'B'	28/07/08
8A – Stream 'A'	04/08/08

3.1.3 Sub-sample Preparation

The parent samples were diluted into sets of sub-samples ranging from tens to thousands of odour units. The sub-samples were prepared prior to E-Nose testing and dynamic olfactometry testing with a panel of qualified assessors. All sub-samples were maintained at a relative humidity ranging between 10% and 20%. A hypothesis was developed during familiarisation phase of this study that the E-Nose may have been affected by variances in the sub-sample gas humidity levels. However, rather than address this issue it was decided this variable all together by standardising the humidity levels in all samples. Preparation was to the following procedure:

1. Parent sample odour concentrations were estimated using dynamic olfactometry for a single round with one assessor (the laboratory technician). This gave a 'ball park' parent sample odour concentration.
2. Sets of four sub-samples of various desired odour concentrations were prepared by diluting the parent sample at various mass flow controller settings using dry, odour-free air from the dynamic olfactometer.
3. One to two sets of sub-samples (four to eight samples) of various concentrations were prepared daily over three to four days per week from the same parent sample received at the start of the week.
4. The sub-samples were prepared so that the concentrations varied by approximately a factor of 4. e.g.. 80 ou, 320 ou, 1,280 ou, 5,120 ou.
5. The sub-samples were immediately stored in a dry-air vessel after preparation preceding testing. This vessel ensured that all of the sub-samples were stored at constant relative humidity and did not adsorb moisture from the room air, given the knowledge that the Nalophan bags are water permeable with time.

3.2 E-nose Odour Testing

3.2.1 E-Nose Mk 3.3

The E-Nose instrument used for this study was an E-Nose Mk 3.3 supplied by E-Nose Pty Limited. The instrument is designed as a real time continuous odour monitor that can differentiate between a range of odour concentrations and characters.

The type supplied to TOU had an array of five hybrid metal oxide chemical sensors tailored to abattoirs, animal yard and rendering plant odours (i.e. "M" version) along with two other sensors for temperature and humidity. The set-up included the standard continuous 'monitor' mode and the optional 'tube-suck' mode that could be selected with a switch. The "monitor" mode was measured to draw air across the sensor array via six holes (i.e. 'nostrils') at a flow rate of approximately 60 l min^{-1}. The “tube-suck” mode was measured to pump air through a tube from a Nalophan odour sample bag directly to the sensor array at approximately 3.3 l min^{-1}. It is assumed both presentation methods produce similar millivolts readings given if the same amount of odour concentration was exposed to the sensors.

Data output was recorded via USB cable to a laptop computer in millivolt units collected at a one-second interval using Picolog software provided with the instrument and upgraded to the current available version. The comprehensive E-Nose specification brochure is provided in **Appendix B**.

The results obtained give an odour measurement measured in milliVolts (mV) for each of the five sensors.

3.2.2 Sub-sample Testing Procedure

Sub-samples were presented to the E-Nose with use the optional ‘tube-suck’ mode locked onto manual operation. The ‘tube-suck’ method was the only feasible way to present the odour to the sensors in a repeatable fashion and without rapidly expending the entire sub-sample. At the commencement of testing, the E-Nose was powered on and allowed to warm-up for at least five-minutes. Presentation and testing was to the following step-wise procedure:

1. E-nose was pre-conditioned with dry, odour-free air from the odour-free air stream of the olfactometer for up to 180-seconds or until the readout from E-nose sensors stabilised;
2. Immediately, the weakest sub-sample was presented for up to 90-seconds or until the readout from E-nose sensors stabilised;
3. On completion of test, the E-Nose was placed onto ‘monitor’ mode to purge sensors with ambient air;
4. Sub-sample returned to dry-air storage to await dynamic olfactometry testing;
5. The procedure was repeated from step one for subsequent sub-samples in ascending odour concentration until the entire batch of sub-samples have been tested.

An example typical readout of a synthetic odour sub-sample has been illustrated in **Figure 3.1**.

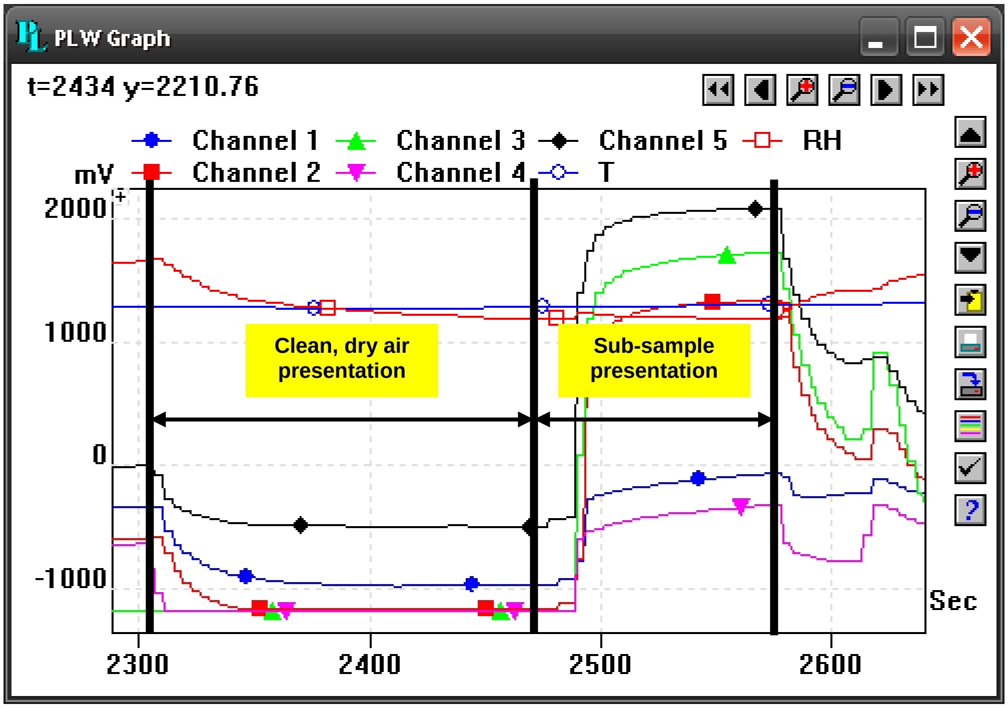


Figure 3.1: Typical E-nose readout for synthetic odour sub-sample

3.2.3 E-nose Sensitivity Settings

The E-Nose testing was carried out at the default sensitivity setting (9) for the first 120 samples analysed. The highest sensitivity setting (15) was used for the remainder 32 samples. All sample mixtures were tested with use of both sensitivity settings. The use of these settings was decided in consultation with E-Nose Pty Ltd.

3.3 Dynamic Olfactometry Odour Testing

TOU's odour laboratory operates to the Australian Standard for odour measurement 'Determination of odour concentration by dynamic olfactometry' (AS/NZS 4323.3:2001) which prescribes a method for sample analysis that provides quality assurance/quality control and ensures a high degree of confidence in the accuracy, repeatability and reproducibility of results.

The concentration of an odour can be measured using a technique known as dynamic olfactometry. Dynamic olfactometry involves the repeated presentation of both a diluted odour sample and an odour-free air stream to a panel of qualified assessors through two adjacent ports on the olfactometer. TOU utilises four to six trained assessors (or panellists) for sample analysis, with the results from four qualified panellists being the minimum allowed under the Australian Standard AS/NZS 4323.3:2001.

The method for odour concentration analysis involves the odorous gas sample initially being diluted to the point where any member of the panel cannot detect it. The assessors step up to the olfactometer in turn, take a sniff from each port, then choose which port contains the odour and enter their response. At each stage of the testing process the concentration of the odorous gas is systematically increased (doubled) and re-presented to the panellists. A round is completed when all assessors have correctly detected the presence of the odour with certainty. The odour is presented to the panel for three rounds and results taken from the latter two rounds, as stated in AS/NZS 4323.3:2001.

The results obtained give an odour measurement measured in odour units (ou). The particular olfactometer used was an Odormat V02 and had complied with the precision and accuracy requirements of AS/NZS 4323.3:2001.

4 Results and Discussion

4.1 E-Nose and Dynamic Olfactometry Results

E-nose testing results for five sensors taken as a cross-section at 90-seconds presentation time as well as odour concentration results for each individual sample are presented in **Appendix C**.

TOU incurred teething issues with methodology development and contamination problems with the olfactometer during week one. Contamination was due to the extremely strong nature of the received parent synthetic odour mixture. This was rectified from week 2 and onwards with the provision of weaker synthetic primary sample mixtures. As a result, week 1 has been excluded from analysis.

4.2 Analysis and Discussion

4.2.1 Synthetic Mixture - Default Sensitivity Setting

A total of 64 data point pairs were gathered on the default sensitivity setting from the standard synthetic mixture. As illustrated in **Figure 4.1**, it can be seen that each sensor responded to various odour concentrations to a log-linear relationship, although each sensor trend line had different gradients. Comments include:

- Sensors 1 through to 4 had little to no response to odour concentrations below 100 to 400 ou.
- Once these thresholds were exceeded positive log-linear relationships were apparent with reasonably high R^2 coefficients suggesting good correlation between the two odour measurement methodologies.
- Sensor 5 was the only sensor to reflect a consistent relationship across the full spectrum of odour concentrations examined (50 ou to 9,740 ou).
- Sensors 2, 3, and 5 appear to be more suited for high odour concentrations up to 10,000 ou with sensors 1 and 4 capable of detection of perhaps up to or over 100,000 odour units.

E-nose sensor readings were grouped into odour concentration ‘bins’ of various ranges starting from less than 100 ou with the range increasing exponentially to take into account the log-linear relationships. For each odour concentration bin the relevant sensor readings were averaged and standard errors between the E-nose readings were calculated. The groupings of odour concentrations were such that olfactometry error should be virtually nullified. This has been presented in **Figure 4.2** as a histogram with error bars reflecting the calculated standard error. This graph also illustrates the E-Nose ‘Odour Fingerprint’ by looking at the ratios between each sensor readings.

4.2.2 Synthetic Mixture - Highest Sensitivity Setting

A limited amount of (8) synthetic sub-samples were run through the E-Nose operated at its highest sensitivity setting. Two notable observations were made from **Figures 4.3** and **4.4**.

The first was, as expected, that the gradient of the trend curves increased substantially across all sensors. Sensors 2 and 3 rapidly maxed out at 2,500 mV once the odour concentration was increased from 200 ou. Sensors 1 and 4 also returned sharp responses above 900 ou. Sensor 5 produced a more moderate gradient, yet sharper compared to the default sensitivity setting, with detection from less than 45 ou to a maximum limit close to 700 ou.

The second observation was that the lowest detection limits of all sensors did not improve when compared to the default sensitivity setting. Apart from Sensor 5, all sensors failed to detect odour concentrations below 100 ou. At the highest setting, the increase of instrument sensitivity was only apparent once the lowest detection thresholds of the sensors were exceeded. In TOUs experience, odour concentrations of less than 100 ou are most commonly experienced in ‘beyond the boundary’ downwind ambient conditions.

4.2.3 Industry Stream ‘A’ - Default Sensitivity Setting

The testing was carried out using two industry primary samples from Stream ‘A’ (rendering plant cooking room ventilation) over two weeks. A total of 32 sub-samples were tested, half during week 5 and half during week 6. Analysis was carried out for each week separately as the collection of the sample was not under controlled operational conditions.

The X-Y scatter plot in **Figure 4.5** and the histogram in **Figure 4.6** reveal that the Stream ‘A’ odour collected for week 5 produced a positive response by the E-nose beyond 300 ou across all five sensors. The trends beyond 300 ou are inconclusive due to the lack of data points however it could be speculated that the relationship is following the same log-linear trends as revealed by the standard synthetic odour.

Similar remarks could be made for Stream ‘A’ that was tested during week 6 displayed in **Figures 4.7** and **4.8**. The only difference was that the odour was not detectable by the E-Nose until it was presented with concentrations exceeding 950 ou. Trends are inconclusive but appear to follow a log-linear relationship.

4.2.4 Industry Stream ‘A’ - Highest Sensitivity Setting

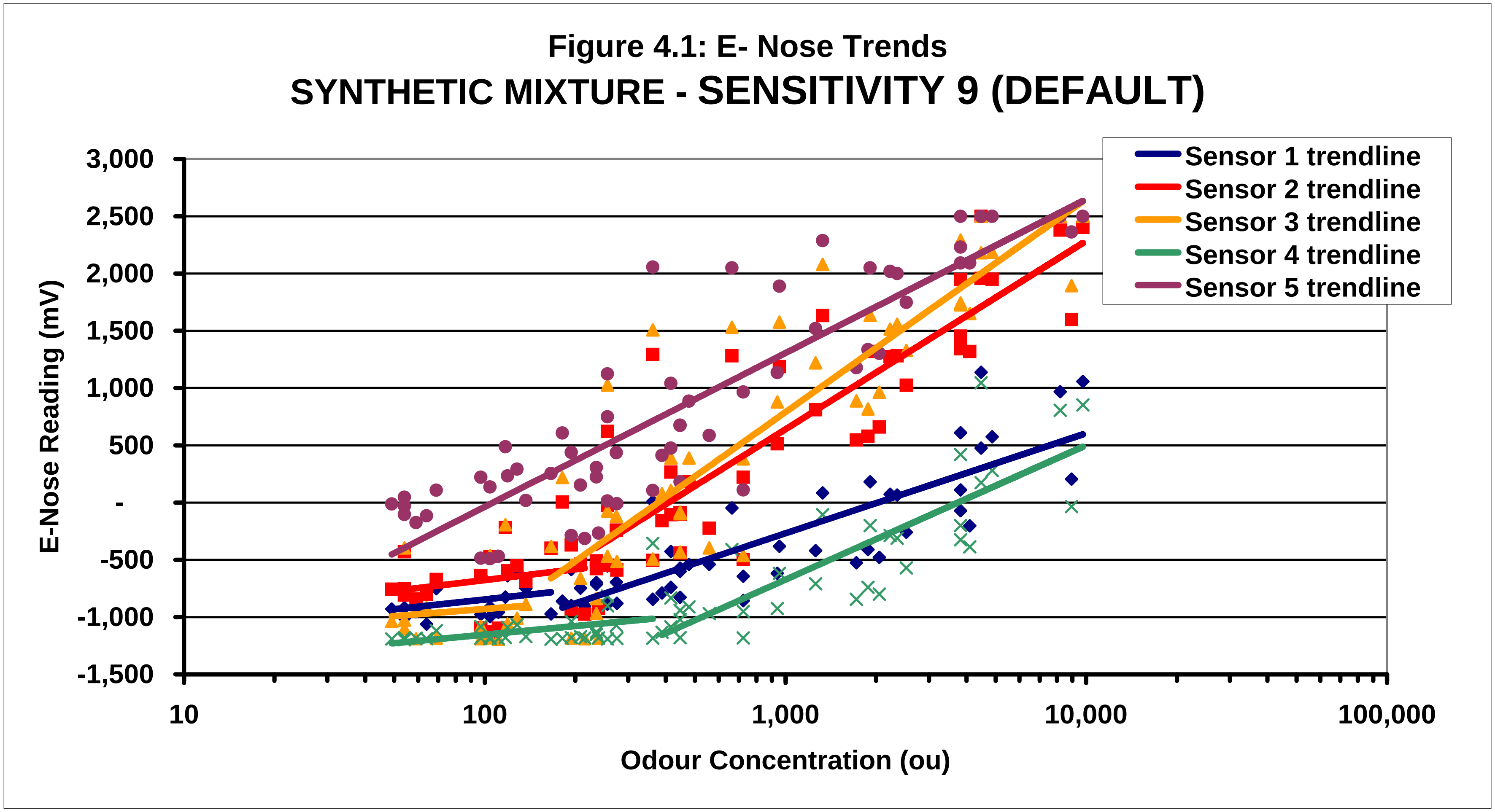
Due to the limited resources, a small number of data points for Stream ‘A’ was collected at the highest sensitivity during week 8. **Figure 4.9** and **Figure 4.10** show a sharp response by Sensor 5 after 750 ou is exceeded. Sensor 1 and Sensor 2 also gave a small response at 3,570 ou, however the indicated relationships are not conclusive.

4.2.5 Industry Stream ‘B’ – Default Sensitivity Setting

A limited number of Industry Stream ‘B’ sub-samples (rendering plant non-condensable gases) was analysed using the E-Nose on default sensitivity setting during week 6 across various odour concentrations. There are positive relationships between milliVolt readings and odour unit measurements across all sensors beyond 750 ou. The exact nature of the trends are inconclusive but are speculated to follow the same log-linear relationship as the synthetic odour. This is illustrated in **Figure 4.11** and **Figure 4.12**.

4.2.6 Industry Stream 'B' – Highest Sensitivity Setting

Sixteen Stream 'B' odour sub-samples were analysed during week 7. Sensors 1 through to 4 did not respond at all to odour up to a concentration of 2,000 ou. Sensor 5 had responded at some point between 200 and 2,000 ou. This may contradict the levels detected in Section 4.2.5 above however this sample was taken during a different production week, which may have had a difference in operational conditions at the rendering plant. A primary sample that was of a differing chemical composition may have been produced that was not favourable to the five hybrid metal oxide sensors. Also, there were responses by Sensor 5 at 26 and 45 ou. No explanation could be made for this and as such the results has been considered outliers. The sensor 5 trend indicated is not conclusive.



Correlation coefficients (R^2) of Sensors 1 to 5 above low detection limit				
Sensor 1	Sensor 2	Sensor 3	Sensor 4	Sensor 5
0.70	0.75	0.76	0.70	0.80

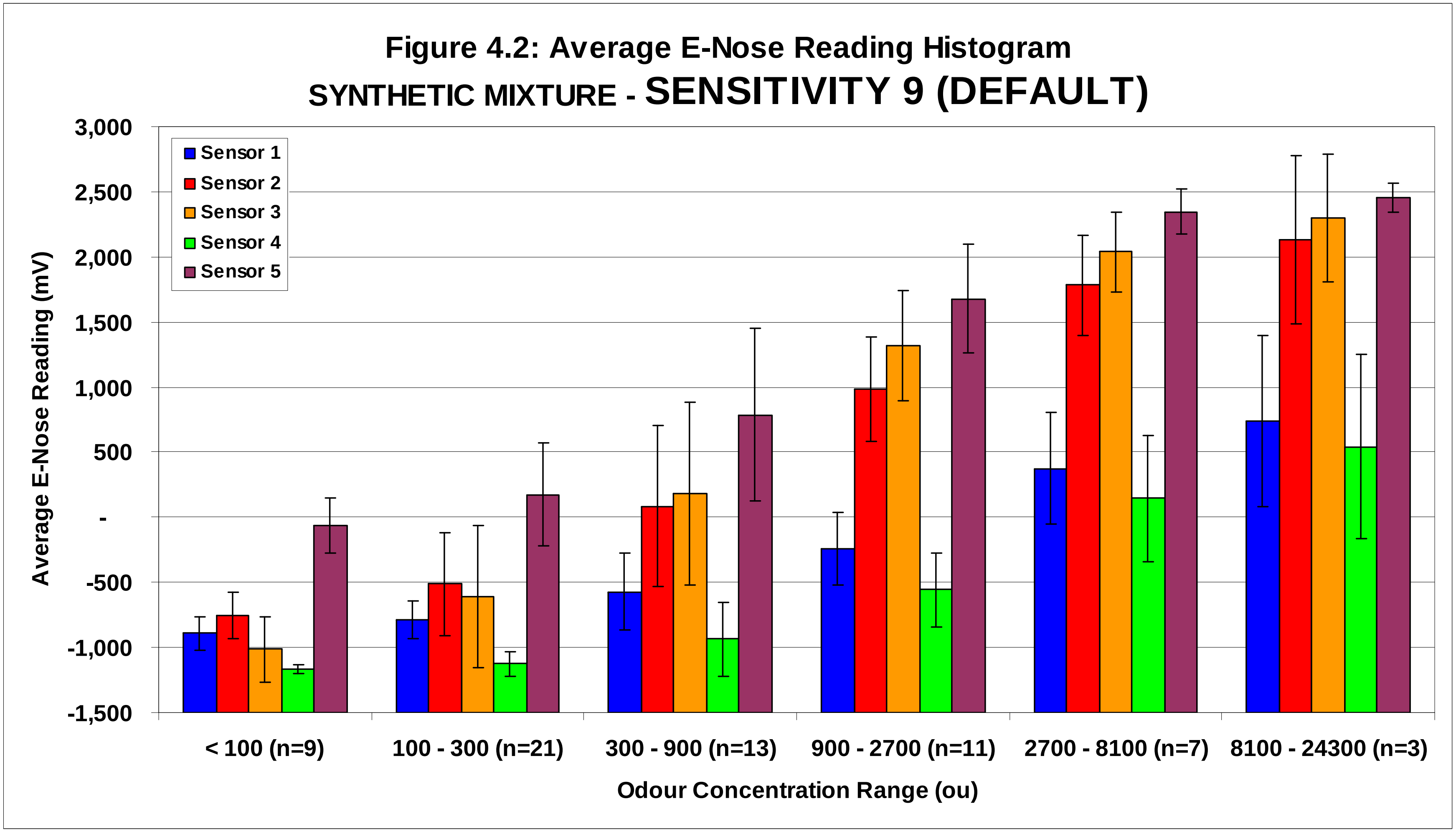
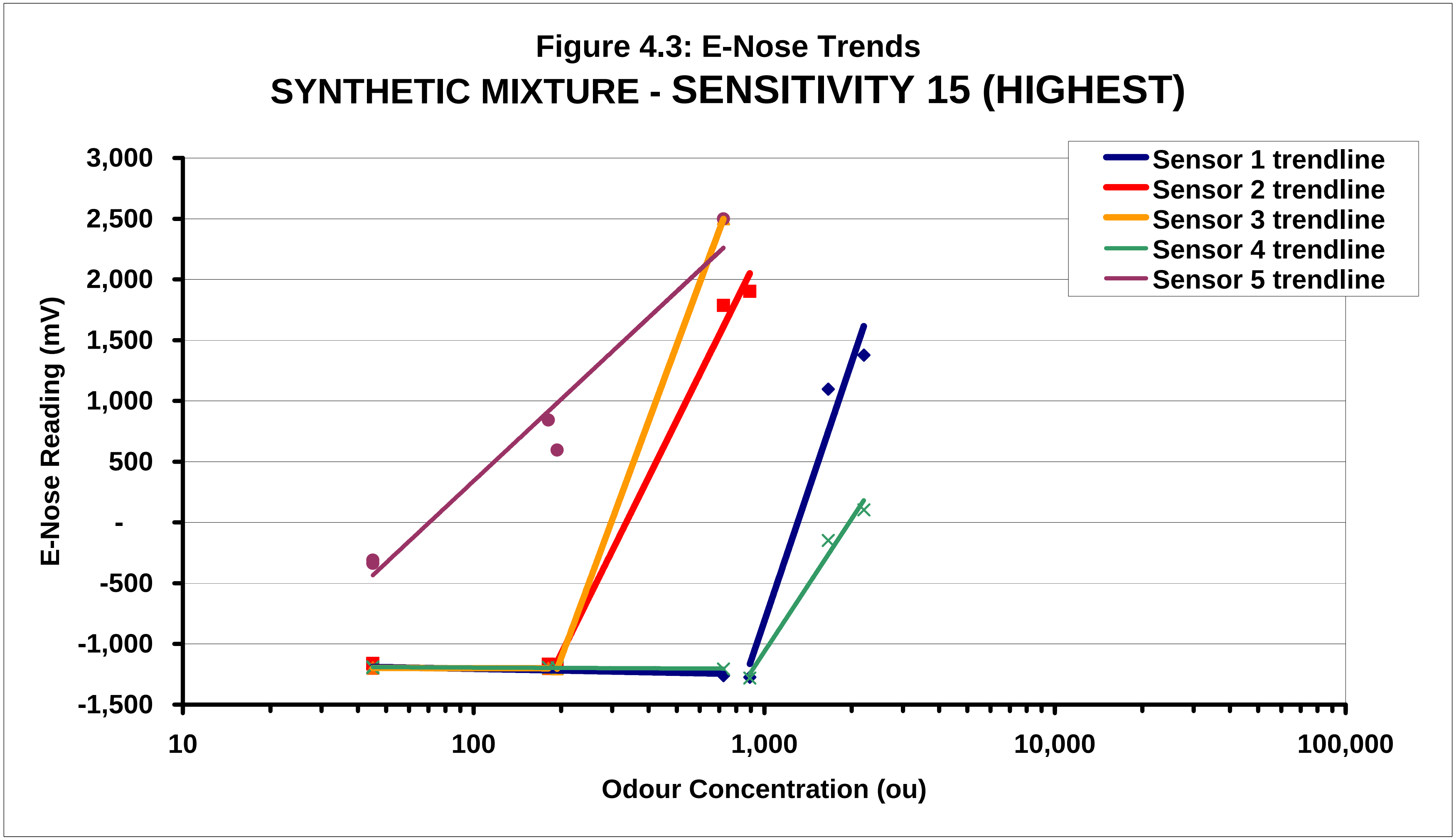


Figure 4.2: Average E-Nose Reading Histogram
SYNTHETIC MIXTURE - SENSITIVITY 9 (DEFAULT)
Sensor 1
Sensor 2
Sensor 3
Sensor 4
Sensor 5
Average E-Nose Reading (mV)
3,000
2,500
2,000
1,500
1,000
500
-
-500
-1,000
-1,500
< 100 (n=9)
100 - 300 (n=21)
300 - 900 (n=13)
900 - 2700 (n=11)
2700 - 8100 (n=7)
8100 - 24300 (n=3)
Odour Concentration Range (ou)



Correlation coefficients (R^2) of Sensors 1 to 5 above low detection limit				
Sensor 1	**Sensor 2**	**Sensor 3**	**Sensor 4**	**Sensor 5**
0.96	0.99	1.0	0.98	0.96

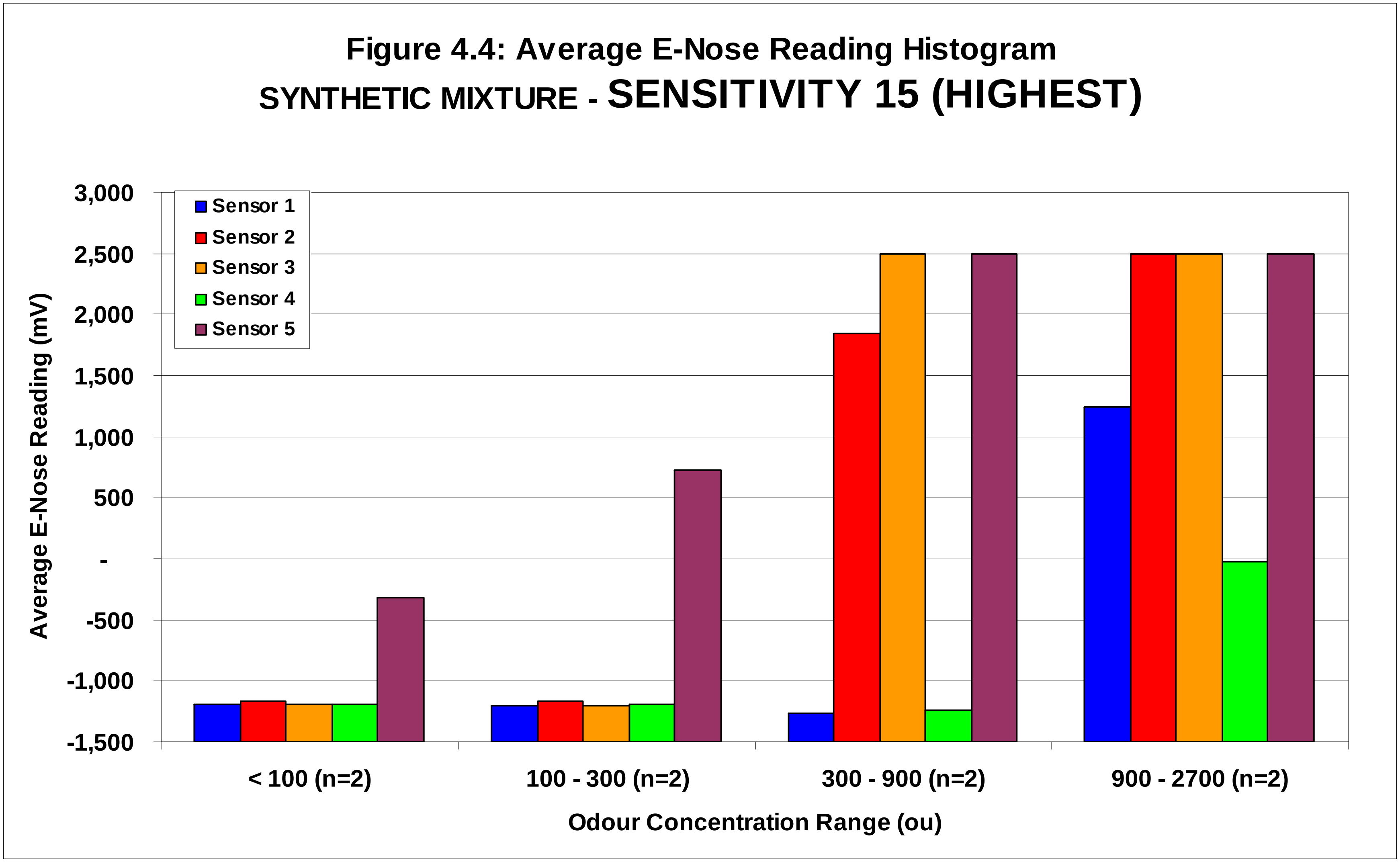
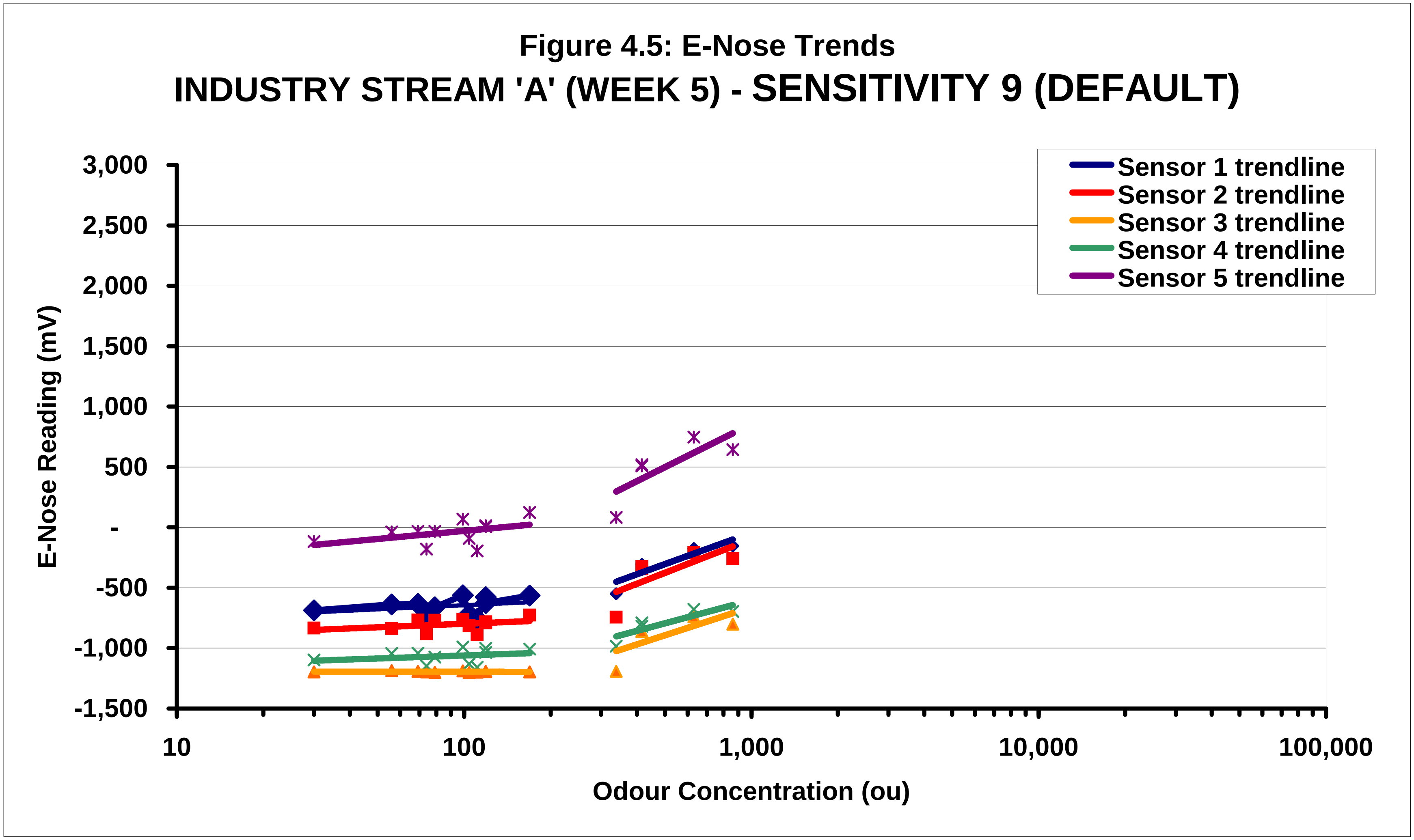


Figure 4.4: Average E-Nose Reading Histogram
SYNTHETIC MIXTURE - SENSITIVITY 15 (HIGHEST)
Sensor 1
Sensor 2
Sensor 3
Sensor 4
Sensor 5
Average E-Nose Reading (mV)
3,000
2,500
2,000
1,500
1,000
500
-
-500
-1,000
-1,500
< 100 (n=2)
100 - 300 (n=2)
300 - 900 (n=2)
900 - 2700 (n=2)
Odour Concentration Range (ou)



Correlation coefficients (R^2) of Sensors 1 to 5 above low detection limit				
Sensor 1	Sensor 2	Sensor 3	Sensor 4	Sensor 5
0.79	0.51	0.52	0.74	0.59

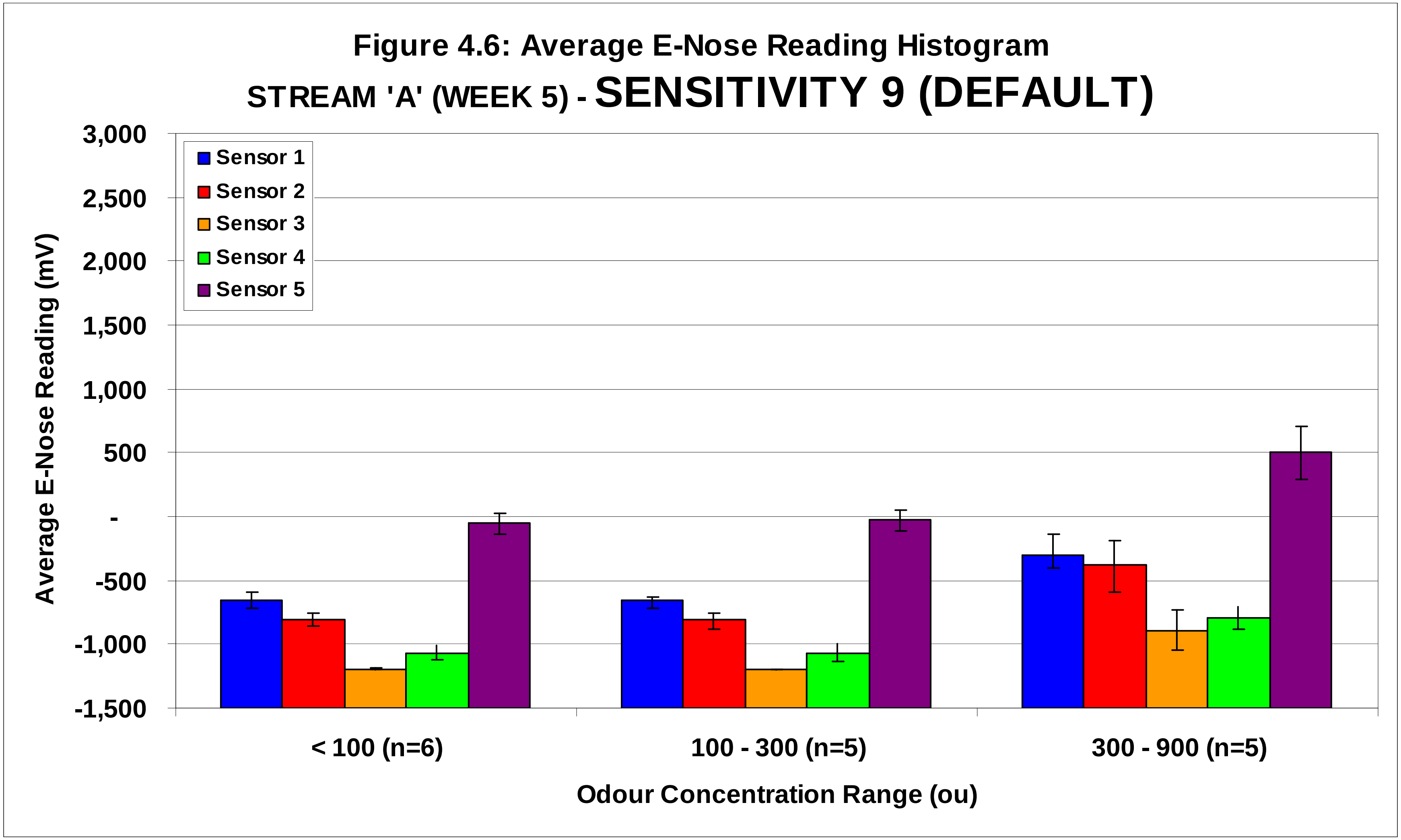
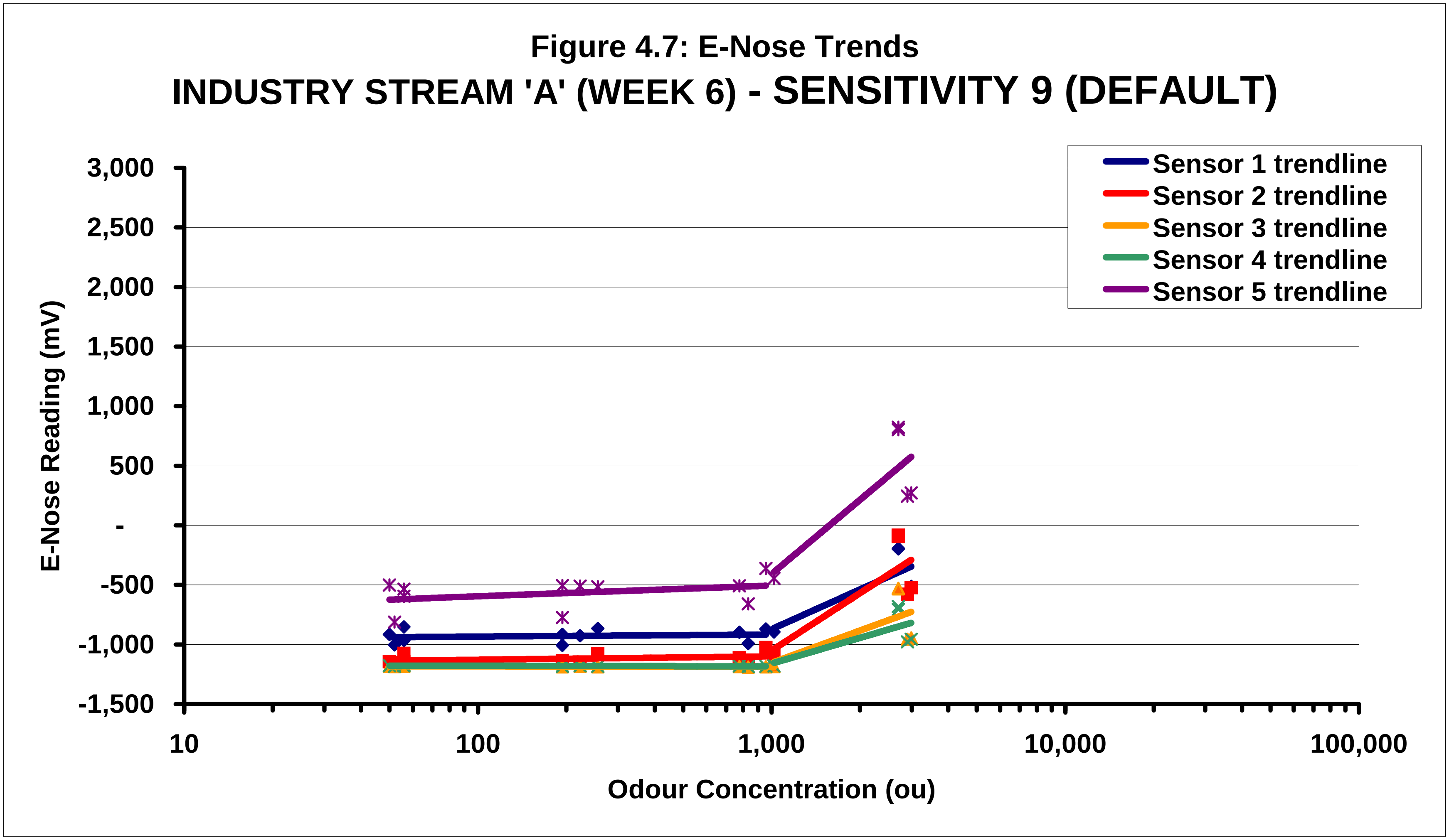


Figure 4.6: Average E-Nose Reading Histogram
STREAM 'A' (WEEK 5) - SENSITIVITY 9 (DEFAULT)
Sensor 1
Sensor 2
Sensor 3
Sensor 4
Sensor 5
Average E-Nose Reading (mV)
3,000
2,500
2,000
1,500
1,000
500
-
-500
-1,000
-1,500
< 100 (n=6)
100 - 300 (n=5)
300 - 900 (n=5)
Odour Concentration Range (ou)



Correlation coefficients (R^2) of Sensors 1 to 5 above low detection limit				
Sensor 1	**Sensor 2**	**Sensor 3**	**Sensor 4**	**Sensor 5**
0.57	0.59	0.38	0.47	0.63

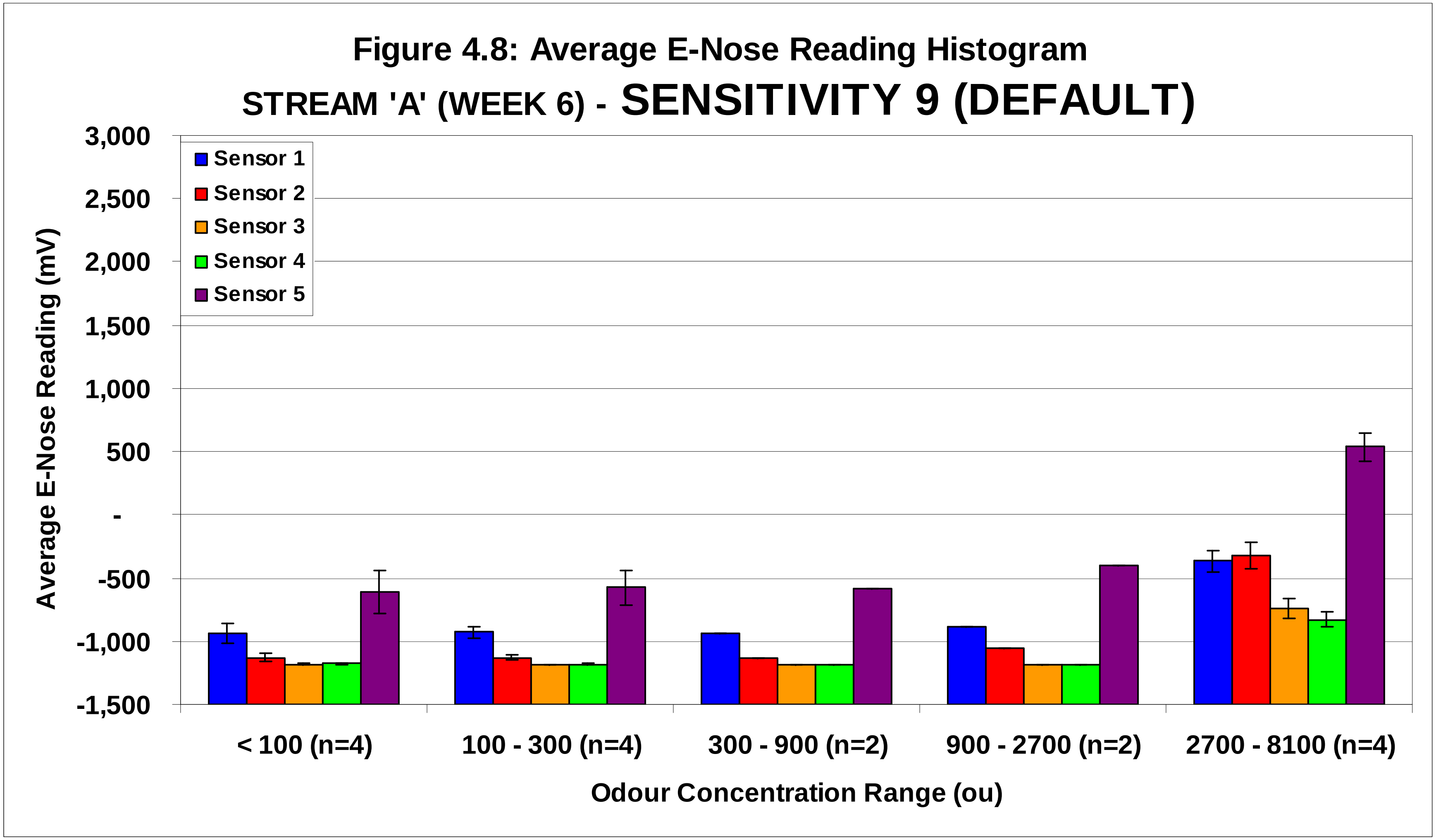
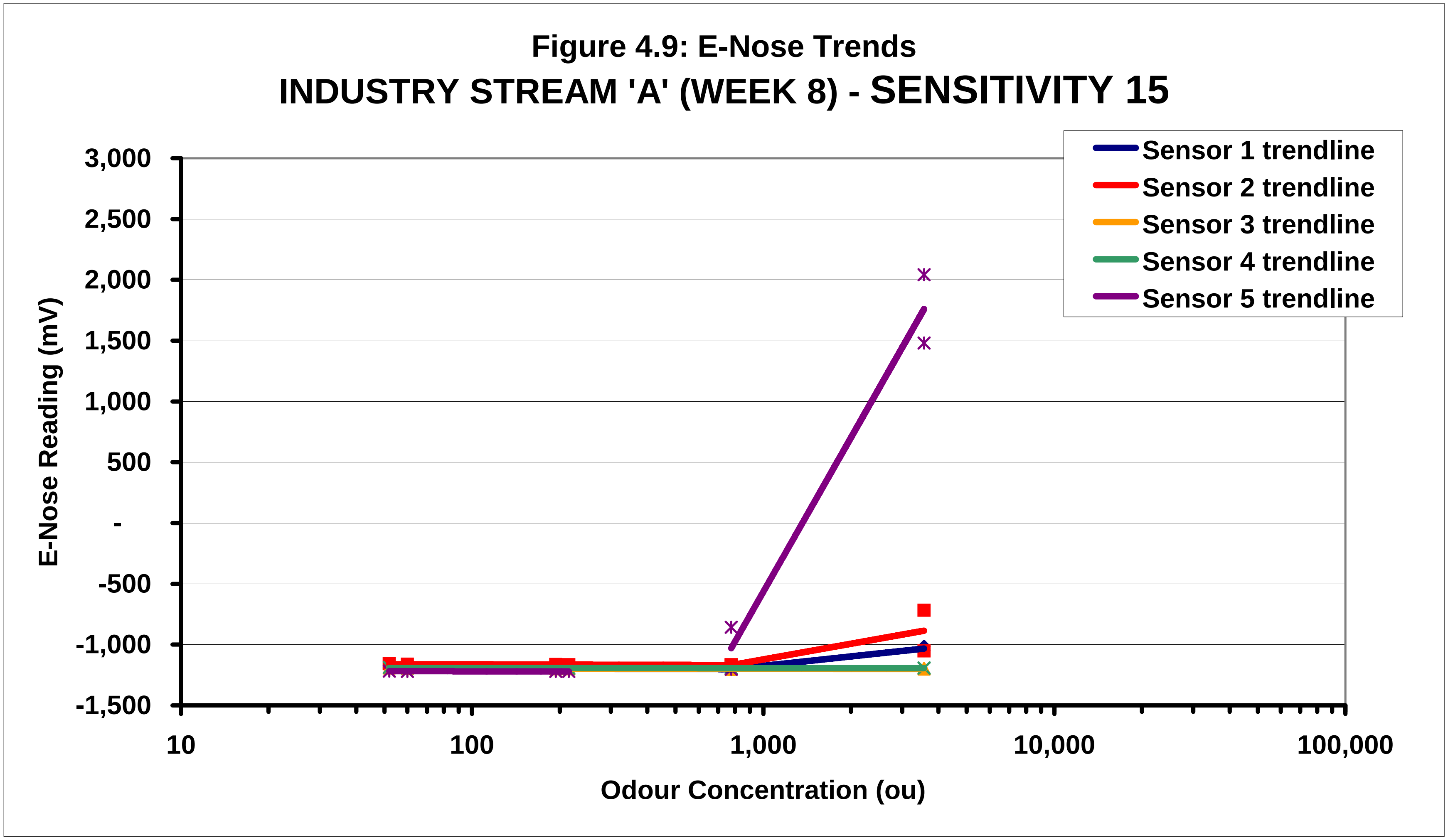


Figure 4.8: Average E-Nose Reading Histogram
STREAM 'A' (WEEK 6) - SENSITIVITY 9 (DEFAULT)
Sensor 1
Sensor 2
Sensor 3
Sensor 4
Sensor 5
Average E-Nose Reading (mV)
3,000
2,500
2,000
1,500
1,000
500
-
-500
-1,000
-1,500
< 100 (n=4)
100 - 300 (n=4)
300 - 900 (n=2)
900 - 2700 (n=2)
2700 - 8100 (n=4)
Odour Concentration Range (ou)



Correlation coefficients (R^2) of Sensors 1 to 5 above low detection limit				
Sensor 1	Sensor 2	Sensor 3	Sensor 4	Sensor 5
0.97	0.49	N/A	N/A	0.97

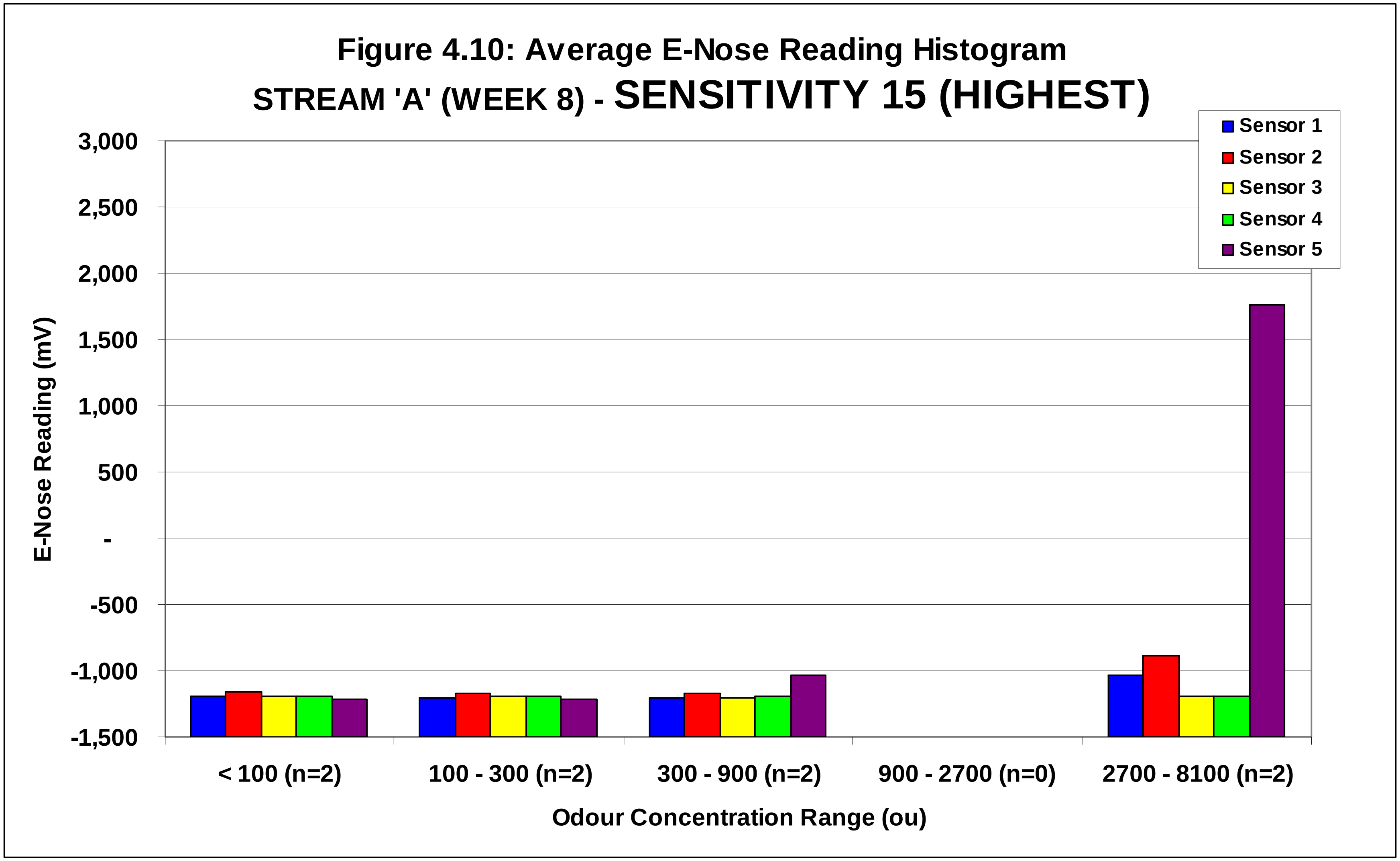
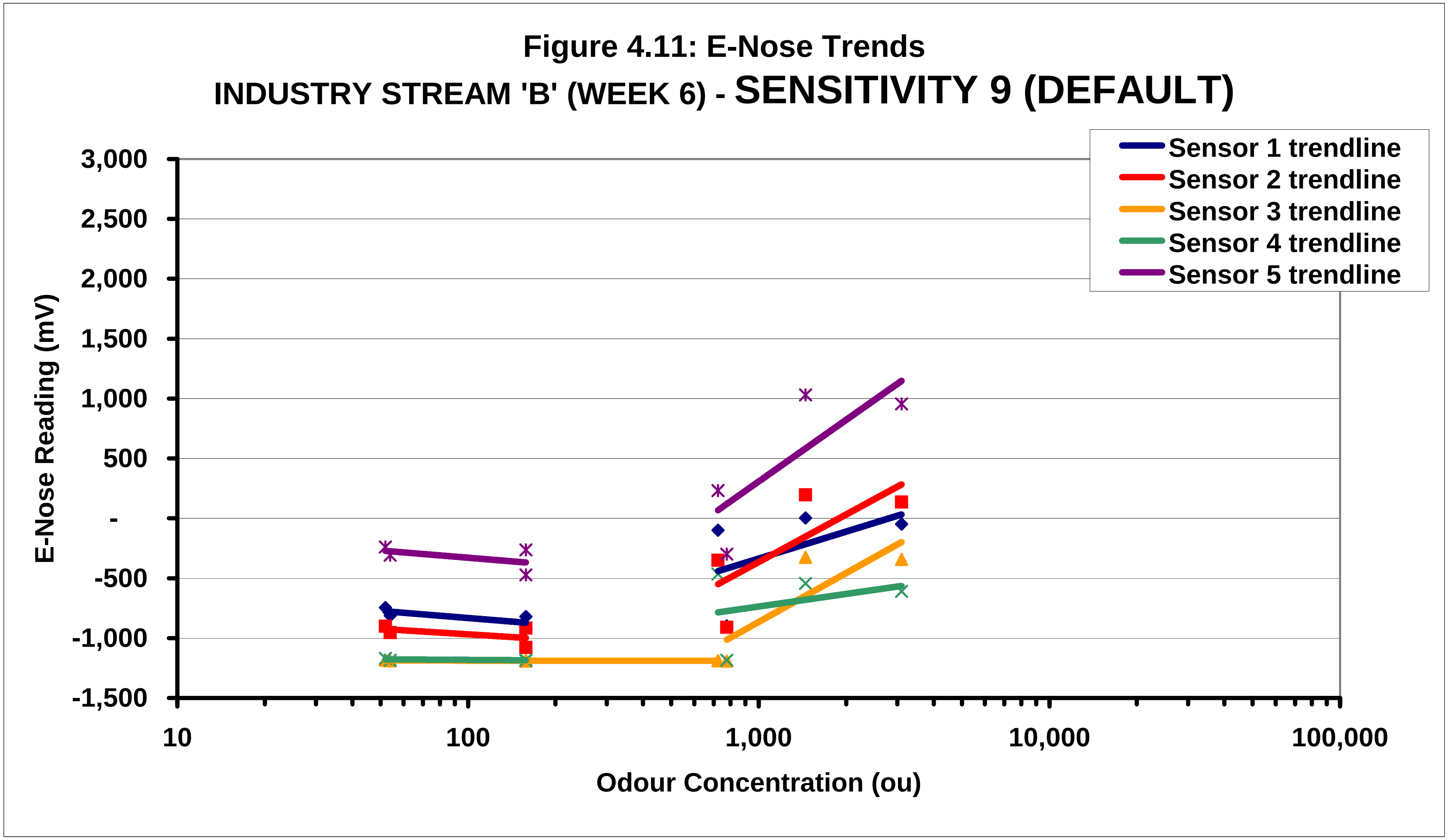


Figure 4.10: Average E-Nose Reading Histogram
STREAM 'A' (WEEK 8) - SENSITIVITY 15 (HIGHEST)
Sensor 1
Sensor 2
Sensor 3
Sensor 4
Sensor 5
E-Nose Reading (mV)
3,000
2,500
2,000
1,500
1,000
500
-
-500
-1,000
-1,500
< 100 (n=2)
100 - 300 (n=2)
300 - 900 (n=2)
900 - 2700 (n=0)
2700 - 8100 (n=2)
Odour Concentration Range (ou)



Correlation coefficients (R^2) of Sensors 1 to 5 above low detection limit				
Sensor 1	Sensor 2	Sensor 3	Sensor 4	Sensor 5
0.27	0.57	0.68	0.098	0.63

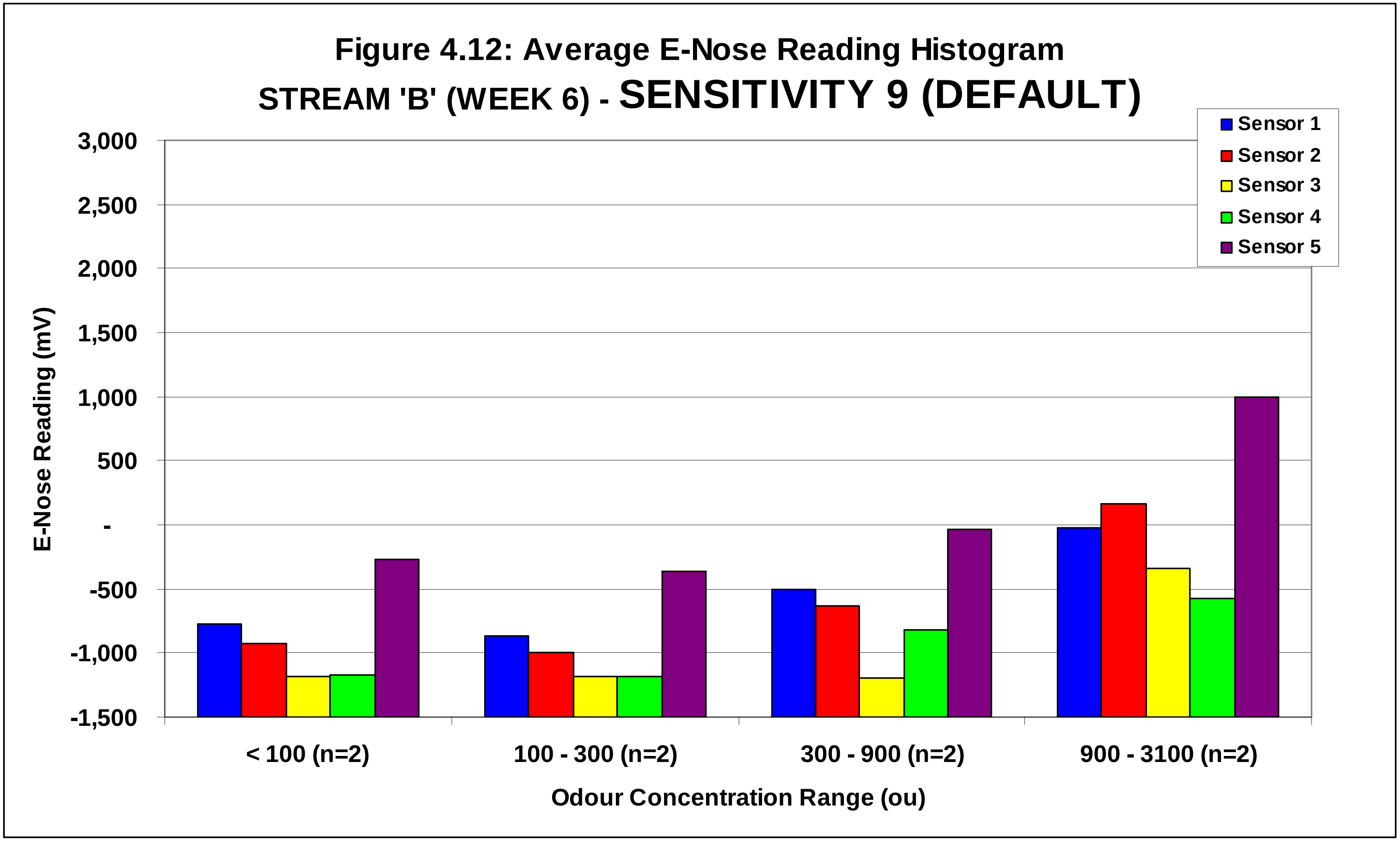
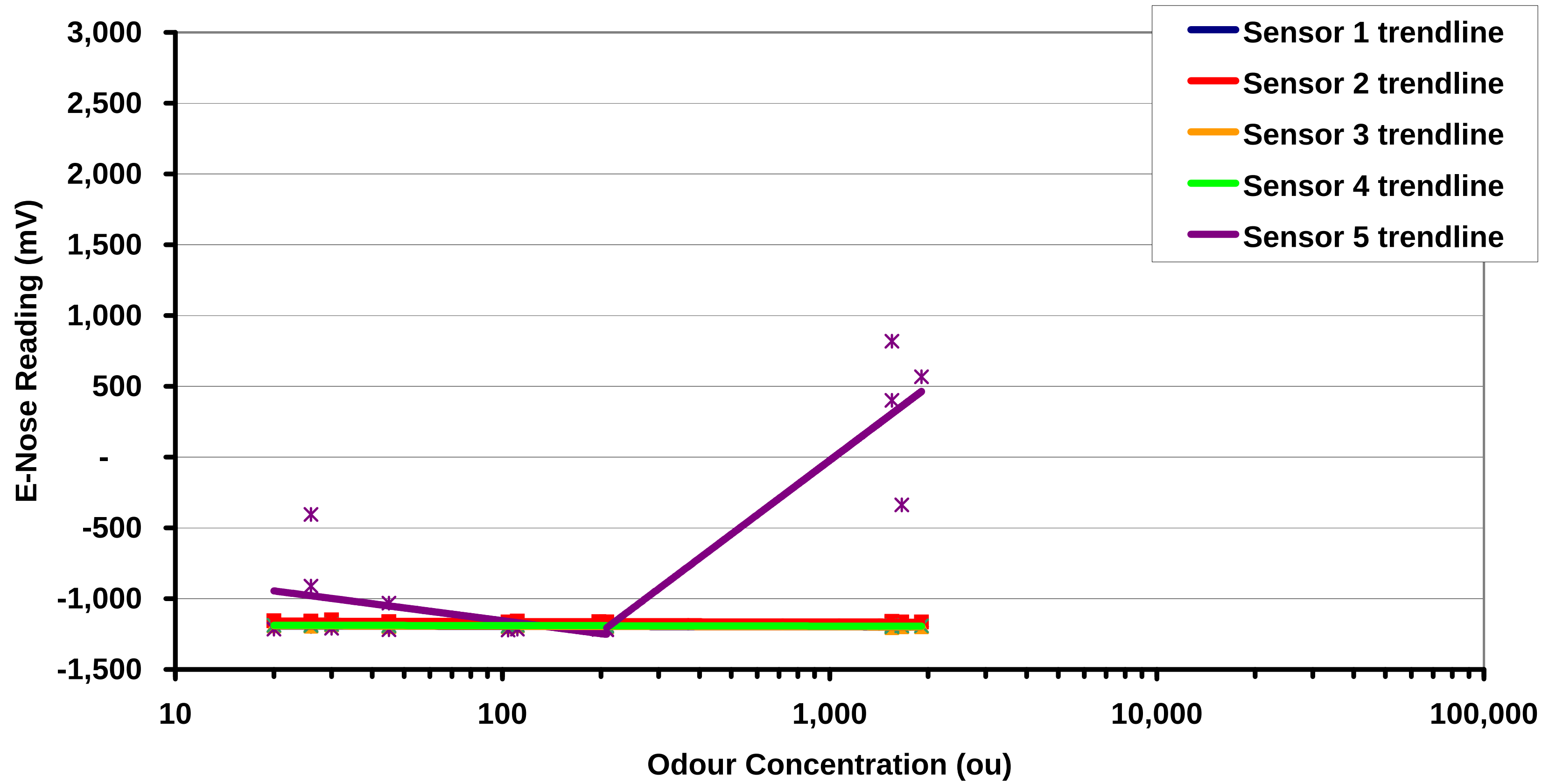


Figure 4.12: Average E-Nose Reading Histogram
STREAM 'B' (WEEK 6) - SENSITIVITY 9 (DEFAULT)
Sensor 1
Sensor 2
Sensor 3
Sensor 4
Sensor 5
3,000
2,500
2,000
1,500
1,000
500
-
-500
-1,000
-1,500
E-Nose Reading (mV)
< 100 (n=2)
100 - 300 (n=2)
300 - 900 (n=2)
900 - 3100 (n=2)
Odour Concentration Range (ou)

Figure 4.13: E-Nose Trends

INDUSTRY STREAM 'B' (WEEK 7) - SENSITIVITY 15 (HIGHEST)



Correlation coefficients (R^2) of Sensors 1 to 5 above low detection limit				
Sensor 1	**Sensor 2**	**Sensor 3**	**Sensor 4**	**Sensor 5**
0.70	0.75	0.76	0.70	0.80

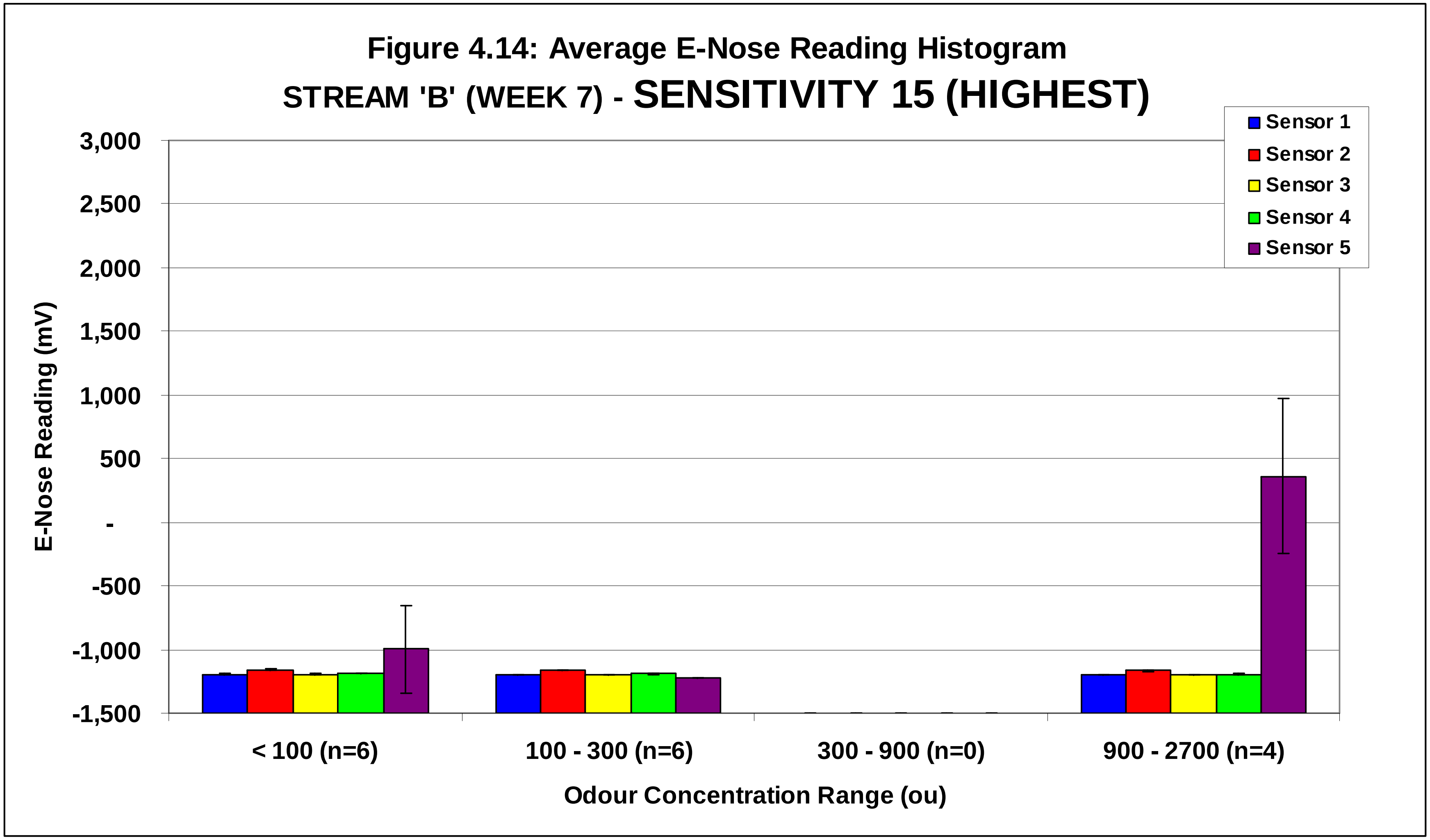


Figure 4.14: Average E-Nose Reading Histogram
STREAM 'B' (WEEK 7) - SENSITIVITY 15 (HIGHEST)
Sensor 1
Sensor 2
Sensor 3
Sensor 4
Sensor 5
E-Nose Reading (mV)
3,000
2,500
2,000
1,500
1,000
500
-
-500
-1,000
-1,500
< 100 (n=6)
100 - 300 (n=6)
300 - 900 (n=0)
900 - 2700 (n=4)
Odour Concentration Range (ou)

5 Success in Achieving Objectives

A core finding of this study was the evidence of a positive log-linear relationship between odour concentration derived from both dynamic olfactometry and E-Nose testing, as determined from the five individual millivolt readings for the E-Nose sensors. No means was provided by E–Nose Pty Ltd of combining the five individual sensor readings into a single or more cohesive way of expressing the instrument's results. However this finding is limited to the standard synthetic rendering mixture and the detection ranges of the E-Nose sensors as illustrated in **Figure 4.1**.

Although Sensor 5 responded to odour at level below 50 ou, (considered representative of downwind ambient conditions of odour impacts) there is uncertainty on whether the sensor had picked up on a mixture of compounds specific to the meat industry or whether it had picked up on common every day compounds that were existent in the synthetic mixture (e.g. 'grassy' odour character that was notable in the synthetic mixture). Until more work is done to determine the specific selectivity of Sensor 5, no confidence in a valid relationship between odour units and millivolt readings can be gained until two or more sensors have responded (i.e. above approximately 200 ou). Furthermore, highest confidence would not be achieved until all five sensors had responded, that is above a threshold of approximately 400 ou. The correlations that had formed above the lowest detection limit of all sensors returned R^2 coefficients of above 0.7 across all sensors.

The R^2 coefficients are considered to indicate good correlations bringing into account the known accuracy in olfactometry measurement, based on the above it is considered that the objective of the study has been achieved. That is, there is validity of converting E-nose readings into to odour concentration readings based on their correlation (millivolts vs odour units).

6 Impact on Meat and Livestock Industry

The core impact on the Meat and Livestock Industry from this study would be a confirmation or otherwise of the Industry's expected application for the E-Nose instrument at the gate/boundary fence line in order to alert the user of upset odour events in real-time. In this respect ***the results indicate that the sensors are not capable of detecting the rendering odour at the required lower downwind ambient concentration levels, even at the highest sensitivity setting***. A possible negative scenario could be the installation of an E-Nose sensor array at the gate/boundary line that does not detect nuisance odour, therefore not alerting the user of upset odour events.

There may be a need:

- to manage expectations from the meat processing industry in regard to the use of the e-nose in areas of low concentration (< 300ou);
- to recommend the use of the E-Nose only to near or at the problem odour sources, where odour levels are within the range of detection, and/or:
- encourage further refinement of the E-Nose 'M' sensors in order to reduce the lowest detection limits.

Notwithstanding the above, the E-Nose can be regarded as a potential complementary tool for future odour emissions management in the meat industry. The E-Nose is fully capable of being installed at or near the source. Its robust 'bulletproof' design, repeatable and continuous high temporal resolution readings and auto-calibration feature give weight to its intended future use as a practical tool for real-time odour monitoring. Threshold limits in the moderate odour concentration ranges could be set on the E-Nose to alert the user of upset odour events in real-time.

At this stage of the instrument's development the application would appear to be at or near the odour source, rather than in the ambient environment. This application would require calibration of the instrument to odour units through a robust regime of odour sampling, testing and a dispersion modelling of the emission source(s) in question. This would require a correlation study of odour concentration with the equivalent E-Nose millivolt readings determined by paired testing using dynamic olfactometry. This can come as an expensive setup cost to the user.

7 Conclusions and Recommendations

7.1 Project Findings

7.1.1 Synthetic mixture testing

The following findings were made:

- There is evidence of a positive log-linear relationship between odour concentration derived from both dynamic olfactometry and E-Nose testing, beyond the lowest detection limit of the E-Nose;
- The millivolt readings for each sensor had independent relationships and gradients versus odour concentration, suggesting that they are responding to different groups of odorant compounds;
- Sensors 1, 2, 3 and 4 had no significant response until the odour concentration exceeded (i.e. lowest detection limits) 200 to 400 ou on the default sensitivity setting;
- Sensor 5 detected the entire range of odour concentrations that were presented (50 ou to 9,740 ou) on both the default sensitivity setting and highest sensitivity setting;
- The change of sensitivity of sensors to the highest setting did not improve lowest detection limits of sensors 1, 2, 3 and 4;
- The highest sensitivity setting did increase sensitivity (i.e. the gradient of the ou/mV relationship) for the sensors once the lowest detection thresholds were exceeded;

7.1.2 Industry mixture testing

The following findings were made:

- There appeared to be a positive relationship between odour concentration derived from both dynamic olfactometry and E-Nose testing, beyond the lowest detection limit of the E-Nose sensors, however the exact correlation was less conclusive;
- There was no significant response from any of the five sensors until the odour concentrations exceed the lower detection limit that ranged from 300 ou to 2,000 ou, depending on the individual sensor;
- There was no improvement in the lowest detection limits when the sensitivities of all sensors was changed to the highest setting;
- Overall, the E-Nose did not detect the rendering plant industry odours as well as it did for the synthetic odorant mixture.

7.1.3 Combined testing

A further finding can be made in relation to all of the testing results:

- The E-nose instrument is not able to quantitatively differentiate between different odour characters, given the limited way in which the sensor results are expressed as five individual millivolt readings. There appear to be qualitative differences in the results for different odour characters, as evidenced by the average E-Nose histogram graphs (compare Figs 4.2 and 4.8), but such a differentiation would be difficult for a typical meat industry user to determine. This further supports the need for further development of the results software, along the lines of a multi-dimensional statistical analysis, executed in real time.

7.2 Conclusions

Based on the methodology used, the experience in the operation of the E-Nose instrument and the above findings, the following conclusions were made:

- There is validity and potential in the converting of E-Nose millivolt readings to dynamic olfactometry odour unit measurements based on their correlation;

- The E-Nose does not appear to be capable of detecting the synthetic or the industry odour at the required low downwind ambient concentration levels, even at the highest sensitivity settings. The use of the E-Nose with the 'M' array of sensors at the gate/boundary fence line in order to alert the user of upset odour events in real-time may not be a realistic expectation.

- The E-Nose in its current configuration would be most suited to being installed to monitor at or near the industry emission sources, where higher odour concentration levels are likely;

- The E-Nose appears to have the ability to detect small changes in odour concentrations when operating beyond the sensors' lower detection limits, a feature beyond the capability of conventional odour sampling and dynamic olfactometry testing;

- The E-Nose sensors were not suitable for detecting the particular meat industry rendering plant odour presented to it during this study.

7.3 Recommendations

Based in the above conclusions the following recommendations are put forward for consideration:

- An advanced multidimensional statistical analysis is suggested with the objective to combine the five unique sensor points into one point and relate that back to odour concentration and perhaps odour character (e.g. Principal Component Analyses.) An outcome of this would be a more simplified interpretation of the odour concentration readings that are the output of the E-nose. Currently interpretation is restricted to assigning trend lines to five individual sensor millivolt reading against a single odour unit measurement;

- In regards to the inability of the E-Nose to detect lower ambient level odour concentrations, it is recommended that MLA consider one or a combination of the following approaches:
  - Provide the Meat and Livestock industry with advice to restrict the use of the E-nose instrument in the Meat and Livestock industry to be at or near the odour emission source and not at the gate/boundary;
  - Determine the odour upset alert level setting of the E-Nose (instrument to be installed at or near the sources) based on the use odour emission sampling, testing and dispersion modelling assessment, complemented by emission source specific millivolt to odour unit correlation testing;
  - Encourage E-Nose Pty Limited to refine the 'M' sensors to detect lower ambient level odour concentrations;

- For E-Nose instruments that are installed at or near the source there would be a need to establish the most optimal sensitivity setting of the instrument. Set correctly, the E-Nose has the potential to detect the more minor fluctuations in odour emission that are not easily or readily detected by conventional odour sampling and dynamic olfactometry;

- Further testing may be required to establish and confirm whether the finding that the E-Nose was unsuitable for detecting the industry rendering odours that were sampled at the industry site was an isolated occurrence or whether it truly represents all rendering odours across the whole industry. Furthermore, testing with other meat industry specific odours such as from abattoirs and intensive livestock feedlots would be useful data to obtain.

8 Bibliography

MLA (1999), Meat and Livestock Australia Research Project RPDA.303 – Environmental Issues Sub-Program, *Investigation of Odorous Gas Emissions From Meat and Rendering Plants*, Project Report – Final

Standard Australia/Standards New Zealand (2001), *AS/NZS 4323.3:2001 Australian/New Zealand Standard Stationary Source Emissions Part 3: Determination of odour concentration by dynamic olfactometry*, Sydney/Wellington.

9 Appendices

9.1 Appendix A – Advanced Analytical Australia Synthetic Odour Preparation Document

Preparation of Synthetic Render Odour.

Report No: A08/2069
Report for Steven Hayes and Terry Schulz, The Odour Unit
Prepared by David Stone
Wednesday October 15, 2008

The Odour Unit desired that a Synthetic Odour be provided in a precise and consistent manner for four successive weeks of trials.

Method.

The formula has previously been published in MLA report RPDA.303 (August 1999).
The odour was selected as broadly representative of the primary render process, often the most significant odour source in rendering plants. The table of chemical constituents and a representative chromatogram are provided below.
Liquids were mixed in the desired proportion as chemical groups; sulphurs, aldehydes, alcohols and ketones; and the appropriate amount of each mixture was injected into a 40 litre Nalothane bag which was being slowly filled with dry Nitrogen, at a rate of 2-3 litre per minute, using a mixing manifold designed for the purpose. The gases components (Hydrogen sulphide; H_2S and Methylmercaptan; MeSH) were introduced from certified standard cylinders (as pre-diluted gases supplied by BOC); 50ppm in the case of Hydrogen sulphide and 5ppm for the Methylmercaptan. Ammonia was added as 33% aqueous solution. The chemical components within the completely filled Nalothane bag was allowed to further mix while being rotated for 30 minutes.

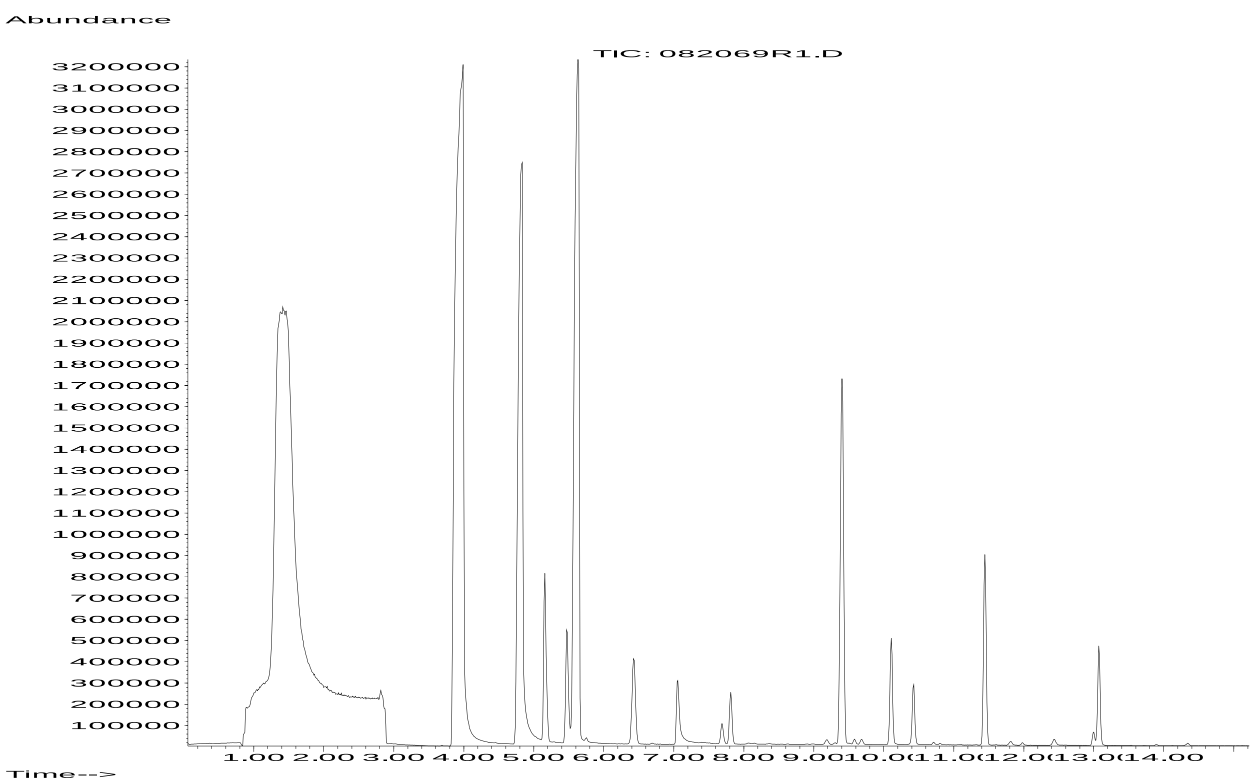
Results.

Compound	Concentration (ppm)	Retention Time
Ammonia	10	1.8
H2S	1.2	1.5
MeSH	0.8	2.1
dms	0.013	5.0
dmds	0.25	9.0
2-methylpropanal	0.68	5.3
2-methylbutanal	3.8	7.9
hexanal	0.41	13.0
methanol	3.04	3.9

ethanol	17.47	4.6
i-propanol	0.84	5.3
propanol	1.02	6.9
acetone	1.1	5.0
methylethylketone	0.085	7.9

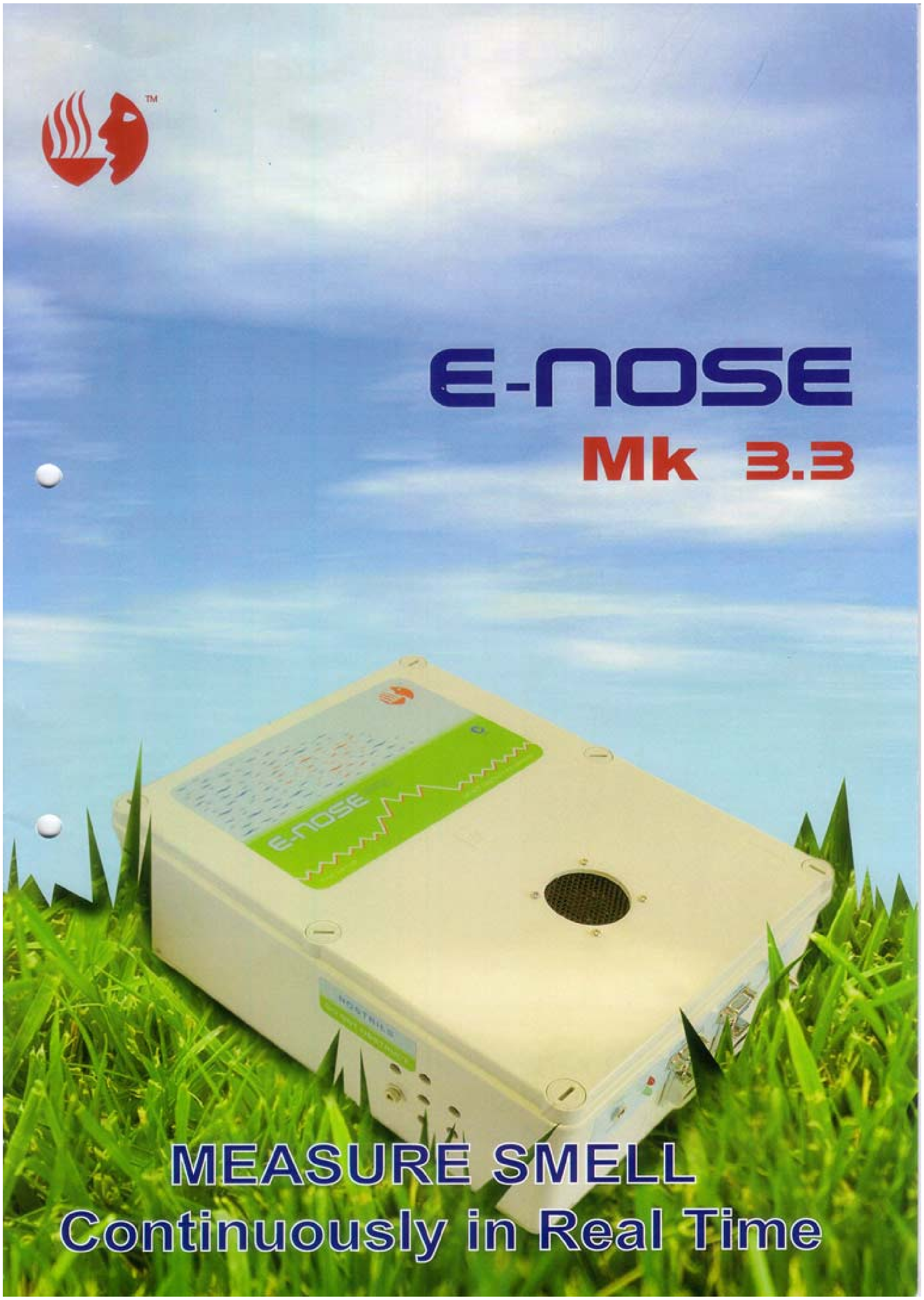
Chromatograms

Figure 1. Chromatogram of Synthetic render odour



David Stone
Senior Scientist
Advanced Analytical Australia

9.2 Appendix B – E-Nose Mk 3.3 Brochure and Specification Sheet



E-NOSE
Mk 3.3

Real Time Continuous Odour Monitor

The Value Proposition

No matter what your problem with smell might be, if you are going to control and manage it, you will need to measure it.

But how do you measure a smell?

Until now, available methods (Gas Chromatograph - Mass Spectrometer and dynamic olfactometry) have required samples of air to be taken back to a laboratory for analysis. Results become available days or weeks later. By that time the smells may have changed or disappeared.

The E-Nose Mk3.3 provides a constant, ongoing and immediate solution to odour and air pollution measurement: It draws air over its sensor array in a constant stream. The sensors deliver ongoing sets of digitised signals representing the chemicals in the air at a rate of one set per second. Immediately, a smell can be identified and an alarm activated or the operator informed.

This allows you to collect and monitor your smell emissions anywhere on site, from the comfort of your office, instantaneously and non-stop, 24 hours a day, 7 days a week, fifty-two weeks a year. You can "see" smells when they are happening, respond to them immediately, and record them permanently.

The E-Nose Mk 3.3 can monitor indoor or outdoor ambient air, or it can suck in air from confined spaces where humans cannot go. It has a range of fifteen sensitivity settings to capture smells that vary in perceived strength from below human threshold to the strongest smells imaginable.

Managing your odour problem becomes easy and inexpensive with instantaneous read-out to the plant operator, or feedback to control equipment. Managing odour need no longer be a hit and miss activity. Running odour abatement equipment, using the E-Nose Mk3.3 as a sensing system for smells in the air, means the equipment operates only when it is needed. The savings from this will add to your business's bottom line and give it competitive advantage.

With E-Nose Mk 3.3 technology in your site management system, you can sleep easier, knowing that your plant and operations are not exceeding emission guidelines and if they are likely to, you will be first to know, not the neighbours or the Environmental Protection Authority (EPA).

Having the technology running continuously and delivering real-time data means your plant management can respond to problems immediately they begin. You can also ignore those that are not of concern to you (e.g. from off-site) saving time and effort on false alarms. You will know immediately where the problem may be coming from, based on the Mk 3.3's patented odour recognition algorithm. With E-Nose Mk 3.3 you will soon develop appropriate management strategies to reduce and eliminate complaints and their associated costs. You will earn the respect of the community and anti-pollution enforcement agencies.

Applications

E-Nose Mk3.3 uses small tailored sensor arrays. They are designed for the environment in which the system will operate. The sensor arrays are located on interchangeable boards inside the main E-Nose device. Currently there are three versions of the array tailored for specific applications:

"M" Abattoirs, animal yards and rendering plants (5 sensors)
"S" Solid and liquid waste; sewage pumping and processing; petrochemical sites (6 sensors)
"I" Vapours from spray-paints & solvents; emission of chemicals from boat-building; security situations involving graffiti vandals (4 sensors)

If the existing arrays are not ideal for your application a new board can be tailored for you after analysis of the smells that are typical at your site.

Portable Application:

Carry the E-Nose around your site to monitor known odour sources and perhaps discover [illegible] ones! A portable 12V battery can give you 2 to 8 hrs of operation. One person can easily carry the E-Nose, its battery and a lap-top. See the results immediately in real time, as you move around.

Static Indoor Application:

Set up the E-Nose in a safe, sheltered spot in the path of known odour or in a place where you need to know what is happening in the indoor space. Use mains power, and a data line to your office computer.

Static Outdoor Application:

Place your E-Nose in a safe, sheltered spot or use a customised B&R lockable, weather-resistant steel cabinet. Use mains power, battery or solar panel to power the device. Use a data line or a wireless data transmitter to relay data to your computer, or a telephone connection and the internet to access data.
Ask your supplier to discuss your most appropriate options, and to quote a price and availability on these accessories.

Auto-calibration:

Mk 3.3 System provides a standard feature of an automatic calibration signal set at a time of your choosing once or twice in 24h, every day or any preferred day of the week. A puff of calibration chemical is made automatically to the sensors and this gives an indication of the functional status of the system.

Alarms:

The system operator can set alarms on all sensors according to experience with events that warrant being alerted. The alarm shows on the screen with a red symbol and an alarm tone sounds until the user turns it off or the odour drops below the designated alarm threshold.

Calibration to Odour Units (OU) or Concentration Units (%SV; PPM/B):

All sensors outputs, normally shown as milli-volts (mV) can be re-scaled to your units of choice by the insertion of an equation into the settings. These equations need to be determined by use of the device in dilution experiments. These can be done by the user, with source materials, or as a service by the manufacturer, for which a fee is payable.

What odours can the device measure?

The device can measure an extremely large number of odours and their concentration variants: theoretically in the order of 6 billion-trillion (6 times 10 to the power of 21). The device takes a "fingerprint" of the odour. If the odour is a mixture of many compounds (as is so often the case in air pollution) it takes that odour's "print". If the odour is a single compound (e.g. H2S) it takes the "print" of H2S. What compounds it detects is limited by the array component sensors.

Why use small sensor arrays, and what sensors are chosen?

Your Mk 3.3 E-Nose is a "tailored array". That is, the number of sensors in the array are no more than 6 sensors. These sensors have been chosen to cover the main components of commonly emitted industrial odours, such as sewage, petrochemical, or abattoir odour. New arrays can be tailored for your specific need. Please contact the supplier for cost and details.

Research has proved that the small number of sensors in the array is an efficient solution to the problem of measuring and identifying odours. Processing is fast, recovery is efficient, poisoning and drift is minimised, redundancy is minimised and part replacement remains cheap and easy. The small arrays do the job they have been asked to do. You are not paying for functionality you do not need.

Optional set-ups of your Mk 3.3 E-Nose

Two additional options are available and are activated by the simple flick of a toggle switch. They require your device to be modified to give you either one or the other (sniff or tube-suck). If you wish to reverse the set-ups, return your device to the supplier for adjustment.

1. Sniff rhythm application Mk 3.3.1

The Mk 3.3 System can be specified to have an additional mode to the standard continuous monitoring mode, wherein the E-Nose can be set to sample air for 1 to 999 seconds before a user specified period of carbon-cleaned air is directed onto the sensors. This "breathing rhythm" can be used to capture and analyse short-lasting odour events. To request the set up of your E-Nose System for this function, please specify Mk 3.3.1.

2. Tube-suck application Mk 3.3.2

Additional to the standard monitoring mode, is the facility to draw a sample of odour in from a 6 metre long tube from spaces that are difficult or unsafe to enter. A common use of the suction tube is sampling from a port in a tank vent, from down a sewer, or at a sampling point in a stack. To request the set up of your E-Nose System for this function, please specify Mk 3.3.2.

Data Display and Recording

Your E-Nose Mk 3.3 comes with a suite of useful software, which is simple to install and allows immediate monitoring, collecting and displaying data.

Your time and date-stamped data can be transferred to Excel for more analysis using it or compatible statistical packages.

New software will be made available to you as it is developed.

Specifications

Weight: 3.1 Kg
Dimensions: 340 x 250 x 120 mm
Sensors: 4, 5, or 6 hybrid metal oxide chemical sensors; temperature; humidity

Power specs
Voltage: 12 V
Consumption: 0.5 to 1.5 amp/h (depends on sensors in array)
Power adaptor: Universal 90/264 V AC external adaptor
Battery: 6-8 amp/h portable enclosed lead-acid rechargeable battery
Recharger: supplied with leads for battery
Data connections: RS232 and USB; Modbus protocol (optional alternative)
Computer compatibility: Generic "IBM" PCs and laptops
SCADA compatibility: when Modbus protocol is requested (user to supply SCADA software interface)
Operating Software required: Windows 98, 2000, XP or Vista
Digital sampling speed (fastest): 1 data set per second; user defined
Display latency: 8 secs from grab to graphic
Data output Units: mV, -2500 to 2500 or as user defined after calibrations, e.g. to Odour Units, PPM/PPB
Memory max: 1 000 000 samples prior to restart/recycle
Number of smell variants detectable: 65,000 to power of 6
Odour Unit range proved: minus 10 to plus 10,000,000 OU
Sampling volume: monitor mode: 0.7m3/min; suck mode: 50L/min
Software: Picolog; E-Nose ODD
Operating temperature: -10ºC to 50ºC
Humidity: recordable: 0-76%RH; operational: 0-100%RH
Warm-up time recommended: 20 min to achieve baseline
Sensor recovery time to baseline after puff of compound: 1 sec to 10 min (concentration and compound dependent).
Sensor life expectancy, running continuously: 2-5 years

Unit service recommended: once every 12 months
Warranty: 12 months

Shipping

E-Nose Mk 3.3 is shipped in sturdy metallic, lockable, instrument case with internal padding.

Your E-Nose Supplier

E-Nose Pty Ltd
145 NIC Bldg
Australian Technology Park
Sydney, 1430
Australia

T: +61 2 9209 4083
F: +61 2 9209 4081
E: g.bell@atp.com.au

www.e-nose.info

9.3 Appendix C - E-Nose and Dynamic Olfactometry Results

Table C.1: Week 1 Results

Sample #	TOU Lab ID	Date analysed	Sensor 1 (mV)	Sensor 2 (mV)	Sensor 3 (mV)	Sensor 4 (mV)	Sensor 5 (mV)	Odour Conc^{n} (ou)
E-nose Sensitivity Setting 9 – Parent Sample 1S "Synthetic"								
1	SI80001	16/06/08	-531	-56	-131	-972	974	388
2	SI80002	16/06/08	-512	469	692	-865	1,424	4,390
3	SI80003	16/06/08	-211	1,450	1,791	-457	2,304	35,700
4	SI80004	16/06/08	462	2,255	2,493	355	2,500	40,300
5	SI80005	17/06/08	-615	-557	-1,117	-1,060	441	111
6	SI80006	17/06/08	-501	-302	-804	-983	753	416
7	SI80007	17/06/08	-450	120	-182	-892	1,138	3,160
8	SI80008	17/06/08	-307	703	707	-694	1,662	30,000
9	SI80009	18/06/08	-529	-526	-1,190	-957	465	293
10	SI80010	18/06/08	-457	-486	-1,132	-903	526	315
11	SI80011	18/06/08	-620	-577	-1,196	-1,045	395	1,780
12	SI80012	18/06/08	-649	-553	-1,200	-1,063	411	477
13	SI80013	18/06/08	-477	-274	-776	-901	700	588
14	SI80014	18/06/08	-402	-198	-727	-848	771	608
15	SI80015	18/06/08	-226	339	422	-672	1,260	549
16	SI80016	18/06/08	-259	360	297	-690	1,283	2,900

Table C.2: Week 2 Results								
Sample #	TOU Lab ID	Date analysed	Sensor 1 (mV)	Sensor 2 (mV)	Sensor 3 (mV)	Sensor 4 (mV)	Sensor 5 (mV)	Odour Conc^{n} (ou)
E-nose Sensitivity Setting 9 – Parent Sample 2S "Synthetic"								
17	SI80017	24/06/08	-752	-672	-1,185	-1,117	109	69
18	SI80018	24/06/08	-554	-27	-74	-900	749	256
19	SI80019	24/06/08	-645	222	381	-951	966	724
20	SI80020	24/06/08	-204	1,319	1,652	-388	2,093	4,100
2S	**SF80002**	**24/06/08**	**Parent Sample**					**55,500**
21	SI80021	25/06/08	-929	-759	-1,038	-1,190	-13	49
22	SI80022	25/06/08	-918	-756	-1,102	-1,199	-32	54
23	SI80023	25/06/08	-1,061	-800	-918	-1,188	-117	64
24	SI80024	25/06/08	-1,009	-807	-1,026	-1,191	-106	54
25	SI80025	25/06/08	-971	-400	-382	-1,193	253	166
26	SI80026	25/06/08	-826	-217	-194	-1,178	488	117
27	SI80027	25/06/08	-49	1,282	1,532	-411	2,050	664
28	SI80028	25/06/08	8	1,294	1,508	-356	2,057	362
2S	**SF80003**	**25/06/08**	**Parent Sample**					**19,500**
29	SI80029	26/06/08	-925	-842	-1,190	-1,184	-176	59
30	SI80030	26/06/08	-912	-472	-463	-1,189	137	104
31	SI80031	26/06/08	-861	4	219	-1,186	608	181
32	SI80032	26/06/08	-382	1,187	1,577	-618	1,890	955
2S	**SF80004**	**26/06/08**	**Parent Sample**					**13,300**
33	SI80033	27/08/08	-822	-430	-397	-1,180	47	54
34	SI80034	27/08/08	-523	622	1,026	-817	1,124	256
35	SI80035	27/08/08	85	1,632	2,082	-108	2,288	1,330
36	SI80036	27/08/08	1,138	2,500	2,500	1,046	2,500	4,470
2S	**SF80005**	**27/06/08**	**Parent Sample**					**13,800**

Table C.3: Week 3 Results								
Sample #	TOU Lab ID	Date analysed	Sensor 1 (mV)	Sensor 2 (mV)	Sensor 3 (mV)	Sensor 4 (mV)	Sensor 5 (mV)	Odour Conc^n (ou)
E-nose Sensitivity Setting 9 – Parent Sample 3S "Synthetic"								
37	SI80037	01/07/08	-749	-687	-889	-1,170	17	137
38	SI80038	01/07/08	-696	-241	-119	-1,073	436	274
39	SI80039	01/07/08	-420	810	1,221	-711	1,520	1,260
40	SI80040	01/07/08	609	1,948	2,293	418	2,500	3,820
3S	**SF80006**	**01/07/08**	**Parent Sample**					**46,300**
41	SI80041	02/07/08	-748	-537	-663	-1,173	153	208
42	SI80042	02/07/08	-541	182	387	-911	886	478
43	SI80043	02/07/08	-71	1,342	1,728	-327	2,093	3,820
44	SI80044	02/07/08	967	2,379	2,500	804	2,500	8,190
3S	**SF80007**	**02/07/08**	**Parent Sample**					**35,100**
45	SI80045	03/07/08	-585	-370	-547	-1,039	438	194
46	SI80046	03/07/08	-426	265	388	-832	1,041	416
47	SI80047	03/07/08	110	1,454	1,744	-201	2,233	3,820
48	SI80048	03/07/08	1,059	2,404	2,500	853	2,500	9,740
3S	**SF80008**	**03/07/08**	**Parent Sample**					**27,600**
49	SI80049	04/07/08	-636	-638	-1,081	-1,084	222	97
50	SI80050	04/07/08	-541	-224	-396	-969	586	558
51	SI80051	04/07/08	-411	579	817	-741	1,336	1,880
52	SI80052	04/07/08	205	1,598	1,894	-37	2,364	8,930
3S	**SF80009**	**04/07/08**	**Parent Sample**					**46,300**

Table C.4: Week 4 Results								
Sample #	TOU Lab ID	Date analysed	Sensor 1 (mV)	Sensor 2 (mV)	Sensor 3 (mV)	Sensor 4 (mV)	Sensor 5 (mV)	Odour Conc^n (ou)
E-nose Sensitivity Setting 9 – Parent Sample 4S "Synthetic"								
53	SI80053	08/07/08	-599	-553	-1,010	-1,066	292	128
54	SI80054	08/07/08	-639	-597	-1,059	-1,091	233	119
55	SI80055	08/07/08	-698	-511	-838	-1,130	306	235
56	SI80056	08/07/08	-715	-579	-967	-1,152	224	235
57	SI80057	08/07/08	-602	-105	-96	-1,022	676	446
58	SI80058	08/07/08	-573	-88	-84	-942	674	446
59	SI80059	08/07/08	-261	1,025	1,329	-572	1,748	2,520
60	SI80060	08/07/08	71	1,276	1,515	-287	2,019	2,230
4S	**SF80010**	**08/07/08**	**Parent Sample**					**77,900**
61	SI80061	09/07/08	-995	-1,130	-1,183	-1,177	-490	104
62	SI80062	09/07/08	-901	-975	-1,188	-1,182	-314	215
63	SI80063	09/07/08	-857	-499	-462	-1,182	109	724
64	SI80064	09/07/08	-480	658	964	-799	1,303	2,050
4S	**SF80011**	**09/07/08**	**Parent Sample**					**53,200**
65	SI80065	10/07/08	-899	-935	-1,185	-1,179	-288	194
66	SI80066	10/07/08	-899	-923	-1,185	-1,182	-267	239
67	SI80067	10/07/08	-827	-442	-432	-1,178	181	446
68	SI80068	10/07/08	-845	-506	-494	-1,185	106	362
69	SI80069	10/07/08	-618	513	879	-924	1,135	939
70	SI80070	10/07/08	-527	546	887	-845	1,177	1,720
71	SI80071	10/07/08	474	1,957	2,181	174	2,500	4,470
72	SI80072	10/07/08	574	1,952	2,186	280	2,500	4,870
4S	**SF80012**	**10/07/08**	**Parent Sample**					**65,500**
73	SI80073	11/07/08	-976	-1,096	-1,190	-1,184	-487	97
74	SI80074	11/07/08	-957	-1,096	-1,194	-1,188	-470	111
75	SI80075	11/07/08	-880	-589	-514	-1,186	-9	275
76	SI80076	11/07/08	-887	-548	-470	-1,190	13	256
77	SI80077	11/07/08	-792	-159	78	-1,133	413	388
78	SI80078	11/07/08	-741	-108	106	-1,085	476	416
79	SI80079	11/07/08	66	1,282	1,557	-312	2,001	2,350
80	SI80080	11/07/08	182	1,319	1,635	-201	2,051	1,910
4S	**SF80013**	**11/07/08**	**Parent Sample**					**61,100**

Table C.5: Week 5 Results								
Sample #	TOU Lab ID	Date analysed	Sensor 1 (mV)	Sensor 2 (mV)	Sensor 3 (mV)	Sensor 4 (mV)	Sensor 5 (mV)	Odour Conc^n (ou)
E-nose Sensitivity Setting 9 – Parent Sample 5A "Industry Stream A"								
81	SI80081	15/07/08	-638	-837	-1,186	-1,044	-38	56
82	SI80082	15/07/08	-579	-791	-1,193	-1,000	14	119
83	SI80083	15/07/08	-551	-742	-1,193	-984	82	338
84	SI80084	15/07/08	-154	-260	-801	-696	644	861
85	SI80085	15/07/08	-562	-761	-1,189	-990	67	99
86	SI80086	15/07/08	-628	-783	-1,194	-1,036	5	119
87	SI80087	15/07/08	-566	-727	-1,196	-1,007	123	169
88	SI80088	15/07/08	-175	-208	-742	-678	746	630
5A	**SF80014**	**15/07/08**	**Parent Sample**					**4,870**
89	SI80089	16/07/08	-635	-768	-1,192	-1,041	-34	69
90	SI80090	16/07/08	-688	-833	-1,198	-1,098	-119	30
91	SI80091	16/07/08	-744	-880	-1,197	-1,147	-180	74
92	SI80092	16/07/08	-661	-769	-1,201	-1,074	-34	79
93	SI80093	16/07/08	-759	-889	-1,198	-1,158	-196	111
94	SI80094	16/07/08	-719	-813	-1,203	-1,131	-92	104
95	SI80095	16/07/08	-329	-324	-864	-819	518	416
96	SI80096	16/07/08	-307	-342	-862	-791	509	416
5A	**SF80015**	**16/07/08**	**Parent Sample**					**2,900**

Table C.6: Week 6 Results								
Sample #	TOU Lab ID	Date analysed	Sensor 1 (mV)	Sensor 2 (mV)	Sensor 3 (mV)	Sensor 4 (mV)	Sensor 5 (mV)	Odour Conc^n (ou)
E-nose Sensitivity Setting 9 – Parent Sample 6A "Industry Stream A"								
97	SI80097	22/07/08	-853	-1,075	-1,182	-1,178	-535	56
98	SI80098	22/07/08	-1,003	-1,152	-1,186	-1,182	-811	52
99	SI80099	22/07/08	-866	-1,076	-1,187	-1,182	-516	256
100	SI80100	22/07/08	-1,009	-1,155	-1,188	-1,183	-774	194
101	SI80101	22/07/08	-896	-1,111	-1,185	-1,180	-508	776
102	SI80102	22/07/08	-991	-1,156	-1,190	-1,185	-660	832
103	SI80103	22/07/08	-512	-524	-944	-956	273	2,900
104	SI80104	22/07/08	-558	-577	-955	-978	245	2,900
6A	**SF80016**	**22/07/08**	**Parent Sample**					**13,300**
105	SI80105	23/07/08	-966	-1,142	-1,176	-1,171	-596	56
106	SI80106	23/07/08	-916	-1,144	-1,183	-1,178	-501	50
107	SI80107	23/07/08	-926	-1,149	-1,183	-1,178	-510	223
108	SI80108	23/07/08	-915	-1,135	-1,186	-1,181	-506	194
109	SI80109	23/07/08	-894	-1,081	-1,185	-1,180	-444	1,020
110	SI80110	23/07/08	-871	-1,026	-1,188	-1,183	-361	956
111	SI80111	23/07/08	-194	-82	-528	-706	803	2,700
112	SI80112	23/07/08	-198	-95	-532	-682	822	2,700
6A	**SF80017**	**23/07/08**	**Parent Sample**					**13,300**
E-nose Sensitivity Setting 9 – Parent Sample 6B "Industry Stream B"								
113	SI80113	24/07/08	-745	-900	-1,184	-1,169	-240	54
114	SI80114	24/07/08	-812	-955	-1,190	-1,185	-308	52
115	SI80115	24/07/08	-821	-917	-1,187	-1,182	-263	158
116	SI80116	24/07/08	-921	-1,079	-1,191	-1,186	-473	158
117	SI80117	24/07/08	-898	-910	-1,191	-1,185	-298	776
118	SI80118	24/07/08	-98	-350	-1,190	-465	232	724
119	SI80119	24/07/08	-49	136	-343	-610	955	3,100
120	SI80120	24/07/08	2	196	-325	-544	1,030	1,450
6B	**SF80018**	**24/07/08**	**Parent Sample**					**7,640**

Table C.7: Week 7 Results								
Sample #	TOU Lab ID	Date analysed	Sensor 1 (mV)	Sensor 2 (mV)	Sensor 3 (mV)	Sensor 4 (mV)	Sensor 5 (mV)	Odour Conc^n (ou)
E-nose Sensitivity Setting 15 – Parent Sample 7B "Industry Stream B"								
121	SI80121	29/07/08	-1,192	-1,157	-1,192	-1,187	-406	26
122	SI80122	29/07/08	-1,196	-1,161	-1,195	-1,190	-911	26
123	SI80123	29/07/08	-1,196	-1,162	-1,195	-1,190	-1,031	45
124	SI80124	29/07/08	-1,199	-1,165	-1,198	-1,193	-1,219	45
125	SI80125	29/07/08	-1,198	-1,163	-1,196	-1,191	-1,218	197
126	SI80126	29/07/08	-1,200	-1,166	-1,199	-1,193	-1,220	208
7B	**SF80019**	**29/07/08**	**Parent Sample**					**10,100**
127	SI80127	30/07/08	-1,185	-1,150	-1,185	-1,181	-1,209	30
128	SI80128	30/07/08	-1,191	-1,156	-1,191	-1,187	-1,215	20
129	SI80129	30/07/08	-1,193	-1,159	-1,193	-1,188	-1,216	111
130	SI80130	30/07/08	-1,199	-1,165	-1,199	-1,193	-1,220	104
131	SI80131	30/07/08	-1,201	-1,166	-1,195	-1,190	-1,218	208
132	SI80132	30/07/08	-1,199	-1,164	-1,197	-1,192	-1,219	208
7B	**SF80020**	**30/07/08**	**Parent Sample**					**4,390**
133	SI80133	31/07/08	-1,195	-1,161	-1,197	-1,191	819	1,550
134	SI80134	31/07/08	-1,198	-1,164	-1,198	-1,192	567	1,910
135	SI80135	31/07/08	-1,202	-1,169	-1,205	-1,199	401	1,550
136	SI80136	31/07/08	-1,199	-1,164	-1,198	-1,192	-338	1,660
7B	**SF80021**	**31/07/08**	**Parent Sample**					**2,200**

Table C.8: Week 8 Results								
Sample #	TOU Lab ID	Date analysed	Sensor 1 (mV)	Sensor 2 (mV)	Sensor 3 (mV)	Sensor 4 (mV)	Sensor 5 (mV)	Odour Conc^n (ou)
E-nose Sensitivity Setting 15 – Parent Sample 8A “Industry Stream A”								
137	SI80137	05/08/08	-1,192	-1,157	-1,193	-1,188	-1,217	52
138	SI80138	05/08/08	-1,196	-1,162	-1,196	-1,191	-1,219	60
139	SI80139	05/08/08	-1,199	-1,164	-1,198	-1,193	-1,220	194
140	SI80140	05/08/08	-1,200	-1,166	-1,199	-1,194	-1,221	215
141	SI80141	05/08/08	-1,200	-1,166	-1,199	-1,193	-1,203	776
142	SI80142	05/08/08	-1,203	-1,169	-1,202	-1,196	-857	776
8A	**SF80022**	**05/08/08**	**Parent Sample**					**13,300**
E-nose Sensitivity Setting 15 – Parent Sample 2S “Synthetic”								
143	SI80143	06/08/08	-1,195	-1,161	-1,196	-1,190	-337	45
144	SI80144	06/08/08	-1,200	-1,166	-1,201	-1,195	-311	45
145	SI80145	06/08/08	-1,201	-1,167	-1,202	-1,194	842	181
146	SI80146	06/08/08	-1,203	-1,170	-1,204	-1,197	597	194
147	SI80147	06/08/08	-1,262	1,786	2,500	-1,206	2,500	724
148	SI80148	06/08/08	-1,274	1,903	2,500	-1,281	2,500	892
2S	**SF80024**	**06/08/08**	**Parent Sample**					**26,600**
E-nose Sensitivity Setting 15 – Parent Sample 7B “Industry Stream B”								
149	SI80149	07/08/08	-1,050	-1,052	-1,196	-1,191	1,479	3,570
150	SI80150	07/08/08	-1,015	-718	-1,201	-1,195	2,043	3,570
8A	**SF80025**	**07/08/08**	**Parent Sample**					**6,650**
E-nose Sensitivity Setting 15 – Parent Sample 2S “Synthetic”								
151	SI80151	07/08/08	1,096	2,500	2,500	-149	2,500	1,660
152	SI80152	07/08/08	1,377	2,500	2,500	104	2,500	2,200
2S	**SF80024**	**06/08/08**	**Parent Sample**					**26,600**