Noise & air quality research in Amsterdam

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Executive Summary

- The unloading of logistics trucks is recommended to be between 10:00 and 12:00 or 14:00 and 16:00 in rainless weekdays, 11:00 and 16:00 in rainy weekdays and before 11:30 in the weekend.
- Both noise and air pollution is estimated to be lower by over 10% on the Marineterrein compared to the average in Amsterdam Centrum.
- Uitmarkt is responsible for the highest noise pollution with a number of peaks of over 80dB observed at Homeland over several hours.
- Lowest noise and air pollution is observed at Shooting range during the evening.
- Worst noise pollution occurs at the Entrance during the evening rush hour.
- Strongest episodes of air pollution are observed at Homeland in the morning due to road traffic and the unloading of logistics trucks.
- Fluctuations in air pollution are stronger than for noise pollution throughout the Marineterrein. Daily variations of air pollution are larger than for noise pollution throughout the Marineterrein.
- Rain and high humidity reduces air pollution throughout Marineterrein. Noise pollution reduces with rain and humidity predominantly at the Shooting range.
- At the Entrance, noise and air pollution are mainly driven by Kattenburgerstraat and road traffic.
- At Homeland, the main sources of noise and air pollution are road traffic, unloading of logistic trucks and people at Homeland.
- At the Shooting range, Scheepskameel and cruise ships are the sources most responsible for noise and air pollution respectively.

Project introduction

The scope of the project is to provide a solution for improving the understanding of the sources of air pollution and noise pollution, as well as decreasing the confusion of the correlation between them. The Marineterrein campus provides a unique combination of road traffic, water traffic, pedestrians, and restaurants, as well as business related traffic such as delivery trucks.

By using a dedicated hardware solution, ULTRA IoT is aiming to validate and locate the sources of noise and air pollution, as well as highlighting correlations between them. Additionally, the solution will provide a quantifiable verification on the validity of the causes of noise complaints. Some of the key issues the analysis will tackle are:

1. What are the main causes of sound & air pollution?
2. How does the weather influence both sound & air pollution?
3. Based on changes in sound direction and quantity, is it possible to differentiate if the sources of noise pollution are static or moving?
4. Based on changes in sound direction and quantity, is it possible to observe if logistic trucks produce problematic amounts of air and noise pollution?

Scientific background

Air Quality

The main air quality pollutants of concern are nitrogen dioxide (NO_2), ground level ozone (O_3) and particulates (PM2.5 and PM10). Each has different sources, health effects and chemical behaviours. In this project air quality was measured using NO_2. NO_2 serves as an effective metric for air quality as it is mostly generated by road traffic, is localised and as it converts or reacts to produce O_3 and particulates. O_3 and NO_2 have been shown to induce adverse human health effects, particularly in the lung, the main point of exposure upon breathing. Epidemiological studies have also shown a close correlation between exposure to ambient PM and an increase in respiratory and heart related disease. Specifics are usually cardiovascular disease, chronic obstructive pulmonary disorder, asthma, and cancer, among others.

According to the European air quality standards (Directive 2008/50/EU), the limit value for the annual mean NO_2 concentration is set at 40 µg/m^3. The 1-hour limit value threshold of 200 µg/m^3 can be exceeded on up to 18 days per year.

Air quality has been classified in this report using the following system:
- Low: NO_2 concentration lower than 20 µg/m^3.
- Medium: NO_2 concentration between 20 µg/m^3 and 40 µg/m^3.
- High: NO_2 concentration higher than 40 µg/m^3.

Noise

According to the findings of the World Health Organisation (WHO), noise is the second largest environmental cause of health problems, just after the impact of air quality.

Environmental noise pollution relates to noise caused by road, rail and airport traffic, industry, construction, as well as some other outdoor activities. Its main symptoms from prolonged exposure include sleep disturbance, cardiovascular diseases, annoyance,

cognitive impairment and mental health problems, in addition to direct effects such as tinnitus. Moreover, noise pollution can cause a substantial depreciation of real-estate value.

WHO Night Noise Guidelines for Europe recommend an annual average night exposure not exceeding 40 decibel (dB). Above 55dB long-term average exposure, noise can trigger elevated blood pressure and lead to ischaemic heart disease.

Noise pollution has been classified in this report using the following system:
- Low: Noise value lower than 50dB.
- Medium: Noise value between 50dB and 70dB.
- High: Noise value higher than 70dB.

Methodology

Noise and air quality were measured using three hardware units that included communication and sensors. Each of the units were composed of 4 directional sound sensors, a temperature sensor, a relative humidity sensor and a NO_2 sensor. The units were located as shown on Figure 1.

Measurements were taken every 5 seconds in order to accurately observe real time trends such as cars going through the Entrance and the unloading of trucks at Homeland. This time interval was also selected as NO_2 converts to other forms of air pollution (mainly O_3 but also PM), with the speed of conversion depending on weather conditions. Usually, the conversion takes around 100 seconds. Therefore, taking measurements every 5 seconds ensures an accurate observation of air pollution.
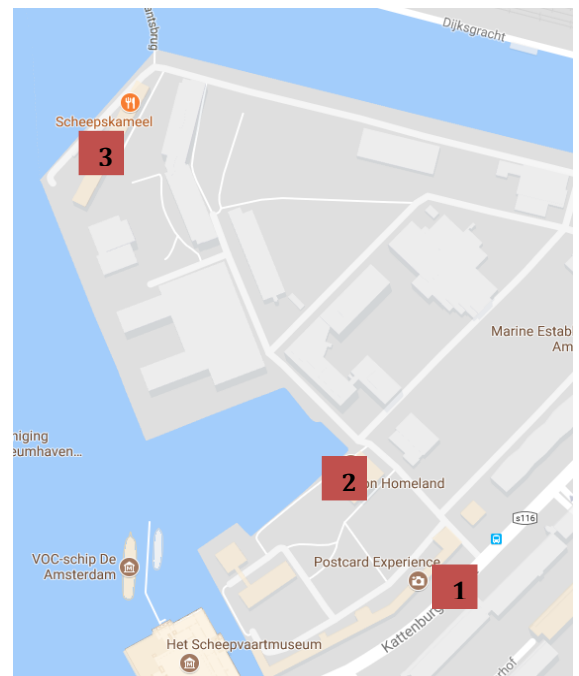

Figure 1: Location of units

Unit 1: Entrance
- Evaluates the traffic from Kattenburgerstraat and the effect of road traffic entering Marineterrein.

Unit 2: Homeland
- Evaluates the loading and unloading of trucks and the noise from people at Homeland.

Unit 3: Shooting range
- Evaluates water traffic and the noise from people at Scheepskameel.

Design

The units were designed in the shape of birdhouse, shown on Figure 2, which allows an active constant flow of air. This ensures the data collected is real-time, due to fans and sophisticated airflow design inside the casing similar to high-end air quality monitors.

Figure 2: Design of units

Research

Noise & air pollution sources

The table below explains the observed most relevant sources of noise and air pollution and their respective impacts and frequency of occurrence.

Colour scheme used to assess the impact and frequenct of sources of noise and air pollution:

● Extremely low   ● Low   ● Medium   ● High   ● Extremely high

Unit	Source	Type	Explanation	Impact	Frequency
Entrance	Kattenburgerstraat	Noise	Demonstrated by the levels of high noise pollution (over 70dB) from the sound sensor directed towards Kattenburgerstraat.	● Medium	● High
		Air	Shown by the higher levels of air pollution compared to the Homeland station in addition to their constancy. This is especially visible when no vehicle enters or leaves the entrance of Marineterrein and in daily air quality averages.	● Medium	● High
	Road traffic	Noise	When a car or truck are entering or leaving the entrance, a shift in noise is observed from one sensor to the opposite one. This can be visualised using data based on a seconds frequency and occurs mostly in the morning and evening during the weekdays.	● Medium	● Medium
		Air	A similar pattern to noise pollution can be observed with air quality. Small increase in air pollution from one sensor in conjunction with noise followed by a shift from the opposite air quality sensor.	● Medium	● Medium
Homeland	Trucks unloading	Noise	Shown by an increase in noise pollution accompanied with an increase in air pollution. This is different from usual road traffic as the impact of both noise and air pollution has a longer timeframe.	● Medium	● High

		Air	Similar pattern to noise pollution. Through this source, air pollution follows noise pollution by 5 seconds.	🔴 (red)	🔴 (red)
	Road traffic	Noise	Noise from road traffic observed in the entrance can be observed a few seconds later at Homeland. This demonstrates that some of the sound pollution from the road traffic entering or leaving Marineterrein is also a source of sound pollution at Homeland.	🟠 (orange)	🟠 (orange)
		Air	Similar pattern to noise pollution. For both air and sound, the rise in pollution from road traffic is accompanied with the other.	🟠 (orange)	🟠 (orange)
	Homeland	Noise	High noise levels during daytime (especially in sunny days, shown by high temperature and low humidity) without raising air pollution concerns are attributed to noise issues from bar and restaurant at Homeland.	🟠 (orange)	🟢 (light green)
	Uitmarkt	Noise	High noise levels (over 80dB) are seen repeatedly in the evening of the event days (25th August till 27th August). The reason these peaks can be distinguished is that the peaks do not come with not strong air pollution and most importantly these peaks are the only ones that are present for a few hours and are much higher than the noise levels recorded at the entrance.	🔴 (dark red)	🟢 (dark green)
Shooting range	Water/rail/road traffic	Noise	Noise pollution occurring every day with respective rise in air pollution is seen at the shooting range and can be attributed to a mixture of water, road or rail traffic. Road traffic is here external to Marineterrein and believed to be generated from Piet Heinkade.	🟢 (light green)	🔴 (red)
		Air	Air pollution daily pattern in conjunction with noise pollution is observed. Its source could be linked to a mixture of water and road traffic. Road traffic is here external to Marineterrein and believed to be generated from Piet Heinkade. The impact of this source of air pollution increases with winds flowing from the water and Piet Heinkade towards the Shooting range.	🟠 (orange)	🔴 (red)
	Scheepskameel	Noise	High levels of noise pollution (over 70dB), especially during weekends (as shown on the 5th, 12th and 19th of August) without increase in air quality can be explained due to people at Scheepskameel.	🔴 (red)	🟢 (light green)

Weather influence on sound and air pollution

The weather strongly influences what happens to air pollution once it's released into the air. During wet or windy conditions, pollution concentrations remain low, either blown away (often called "transport"), or removed from the air by rain (often called "wet deposition"). During still, hot weather, air pollutants can accumulate to elevated concentrations that can be damaging to human health.

As expected in all units, rain, as well as high humidity, significantly reduces the concentration of NO_2. One sample that evidences this can be observed on 17th of August (partially rainy day) where air pollution reduced by over 30%.

In some instances, air pollution is highest in the morning because of the traffic before the sun is at it's strongest. This occurs as NO_2 converts to O_3 and PM and this conversion (especially from NO_2 to O_3) increases in rapidity in the presence of sun. Consequently, in the presence of sun, when NO_2 decreases there is likely an increase in O_3, and thus do not necessarily mean that air pollution reduced. However, by taking measurements every 5 seconds while the average conversion time is 100 seconds, this issue was minimised.

Entrance
- Humidity levels are lower by approximately 5% (especially when wind is favourable) than in the other units. This has a small effect on worsening air quality as humidity absorbs some of the harmful components.
- Rain doesn't influence the level of noise pollution. Using the example of the partially rainy day on 17th August, no observable differences can be seen from other days with regards of noise pollution.

Shooting range
- Rain significantly reduces noise pollution. Demonstrated by considerable lower values (reduction by over 10dB) in noise from the direction targeted at the Scheepskameel. Less people outside of the restaurant/bar or less boats are believed to cause this reduction.
- Wind direction and strength affects air quality. In some circumstances, air quality at the shooting range is unusually significant. After conducting primary interviews with a number of locals, this is believed to be cause by cruise ships, with the winds going from the water towards the Shooting range.
- Extremely strong winds (20mph and above) reduce air pollution at Shooting range.

Distinguishing sources of sound pollution between air and water traffic

With the current setup, it is not possible to distinguish the sources of sound pollution between air and water traffic based on changes in air quality and sound. Further research may be required to provide additional information on this area. Based on primary research, the small amount of sound coming from air traffic can be attributed to two possibilities:

Firstly, air pollution cause by air traffic may need to be measured using another set of components, as air traffic uses fuels that emit different concentrations of NO_2. Air quality pollution caused by air traffic poses concerns through ultrafine particulates. The

second possibility is related to the small extent of air traffic above Marineterrein, resulting in no observable data for noise and air quality pollution.

Differentiating sources of sound pollution between static and moving

The proposed setup allows to easily distinguish between static and moving sources or air pollution because the sensor measurements have been taken every 5 seconds, providing an accurate timing resolution with high granularity.

A moving vehicle (such as a car, truck or boat) can be distinguished due to its noise and air quality surge, shown especially at the Entrance and Homeland. On the other hand, static can be observed by constant sound pollution without any associated increase in air quality, which can be observed at the Entrance and at the Shooting range.

At the Entrance, moving sound pollution is generated from vehicles from road traffic, while static pollution comes from Kattenburgerstraat. At Homeland, moving sources are vehicles from road traffic and trucks unloading, while the main static source is the people at Homeland. In the Shooting range, moving sources of sound pollution are vehicles from road, rail and water traffic, while Scheepskameel is responsible for static sound pollution.

Logistics trucks unloading

Logistics trucks unloading can be observed from both data on air pollution and noise from the Entrance and Homeland units. The best way to identify the unloading of trucks is by taking the noise and air pollution at Homeland as their impact lasts much longer (over 60 seconds more) than with normal road traffic, as the truck needs to stop and briefly remain static. Using this information, the flow of trucks unloading can be traced back to the entrance.

Recommendations:
- During sunny rainless weekdays, we suggest the logistics trucks to unload either between the morning rush hour and lunchtime (from 10:00 to 12:00) or after lunch and before the evening rush hour (from 14:00 to 16:00).
- During rainy weekdays, we suggest the logistics trucks to unload anytime between the morning and evening rush hours (from 11:00 to 16:00).
- During weekends, we recommend the logistics trucks to unload before lunchtime.

The reasoning behind these suggestions is that in sunny rainless days, noise pollution is already at high levels due to the people at Homeland. Thus, unloading the logistics trucks at that time poses a health hazards to these people due to air pollution as well as resulting in a peak in noise pollution from the combination of sound from the people and the unloading of the trucks.

In addition, the morning and evening rush hours are a strong source of air and noise pollution. Thus avoiding them for the unloading of logistics trucks would be beneficial in order to prevent the occurrence of unnecessary peaks.

Uitmarkt

Uitmarkt took place on the Marinetereein between the 25th and the 27th of August. This event had strong influence on the sound and air pollution at the Marineterrein. The peak

of noise levels, with extremely high noise levels (over 70dB and even sometimes over 80dB) are seen repeatedly at the Homeland the 25th night and the 26th and 27th afternoon and night. The peaks were observed the 25th at 22:00, the 26th between 17:00 and 18:00, and the 27th between 16:00 and 18:00. Noise levels at the entrance also grew but not as significantly as at Homeland.

Throughout those days, the strongest peaks of air pollution at Homeland were observed in the morning (08:00 to 10:00) at around 60 μg/m^3. Despite these significant levels of air pollution, it is extremely positive that these peaks do not occur in the same time as when most people are on the Marineterrein for the event. It is noteworthy to point out that the air quality at the Entrance during Uitmarkt and for the couple of days after grew by approximately 15%. In addition, at Homeland, strong noise pollution (over 70dB) was observed the 28th August between 10:00 and 11:00 and the 30th August between 06:00 and 07:00.

Key takeaways

- Over 12 million data points were processed for this analysis.
- The unloading of logistics trucks causes serious implications mainly to air pollution but also to noise pollution. In order to minimise its impact (on Homeland and the whole of Marineterrein) and the occurrence of peaks, we recommend avoiding unloading during lunch time as well as the morning and evening rush hours during the week. During the weekend, the unloading of trucks is suggested anytime before lunchtime.
- On average, the quietest and cleanest location in Marineterrein is the Shooting range in the evening.
- The strongest sources of noise pollution are activities on the Marineterrein such as Uitmarkt.
- The strongest sources of air pollution are cruise ships and trucks unloading.
- On average, air pollution on the Marineterrein is over 10% lower than the one observed by urban stations throughout Amsterdam.
- Sunny and warm weather has the tendency to increase both noise and air pollution throughout the Marineterrein.
- Entrance:
  - On average the highest noise and air pollution in Marineterrein.
  - Air pollution occurs between 08:00 and 20:00, with the highest levels observed usually during the morning rush hour by around 10%. However, in few cases peaks greater than 40 μg/m^3 are observed in the evening rush hour (17:00 and 19:00).
  - During the week, noise pollution is at its highest from 12:00 to 16:00.
  - During weekends, noise pollution reduces by 15% and the occurrence of peaks reduces significantly.
  - During weekends, air pollution is at its highest in the evening.
  - Kattenbrugerstraat is the source of the background noise and air pollution with the traffic at the Entrance source of the peaks.
- Homeland:
  - Air pollution is high in the morning rush hour than in the afternoon/evening one by around 10 – 20 %.
  - Noise pollution is at its highest between 08:00 and 12:00, while air pollution is between 07:00 and 11:00.

- In most days, noise pollution peaks during the morning rush hour. Except during sunny days where it stays almost constant throughout the day due to the presence of people in Homeland.
- Noise pollution fluctuates in a much stronger way than air pollution.
- Noise pollution increases by over 15% in weekends during the day compared to weekdays due to the presence of people on the Marineterrein and Homeland.
- Similarly, noise pollution increases by over 20% in hot and sunny days driven by the presence of people on the Marineterrein and Homeland (such as between the 18th and 20th of July).

- Shooting range:
  - Lowest observed noise and air pollution in Marineterrein, with the least amounts of variations between different days.
  - The level of noise pollution is at its highest throughout the day, remains almost constant and peaks between 12:00 and 15:00.
  - The main sources of noise pollution are Scheepskameel in addition to water, road and rail traffic.
  - Air pollution is strongly driven by weather conditions.
  - Air pollution increases by 10% in the weekends and by over 20% in hot and sunny days. Water traffic is believed to be the main source of this.
  - Extremely strong winds (20mph and above) reduce air pollution.

Further research

Understanding the yearly profile

The analysis on noise and air pollution carried in this report was during the summer and does not capture the trends occurring throughout the year. There is a substantial difference in air and noise pollution between summer and winter, due to change in temperature, change in sun intensity, change in meteorology, and change in peoples habit, among others. For example, air pollution is predicted to increase in winter when low winds lead to a build up of traffic pollution. As a consequence, carrying the analysis in some of the months of the remaining of the year would be beneficial for generating a yearly profile better matching reality.

Wind strength and direction

One of the main factors identified which influences air quality is wind direction. Carrying on the research including wind strength and direction could generate additional correlations between air and noise pollution, their respective sources and impacts. This information could be useful in order to devise preventive actions in case of high probability of cases of strong air and noise pollution.

Improved air pollution profiling and its health impact

The air pollution profile generated focused on measuring NO_2 every 5 seconds as it is localised and converts to the other two most impactful pollutants (O_3 and PM). Each of these (NO_2, O_3 and PM) impacts health through different symptoms and strengths. Since weather conditions strongly affect the conversion of NO_2, it is complex to predict the concentrations of O_3 and PM only from NO_2 concentration. Therefore, in future research, we suggest to include O_3 and PM sensors to further improve the profiling of air pollution as well as accurately quantifying its health impacts.

Air traffic

Assessing issues arising in air quality from air traffic in order to validate its impact on noise and air pollution. This can be done by using additional particulates sensors as well as conducting additional primary research.
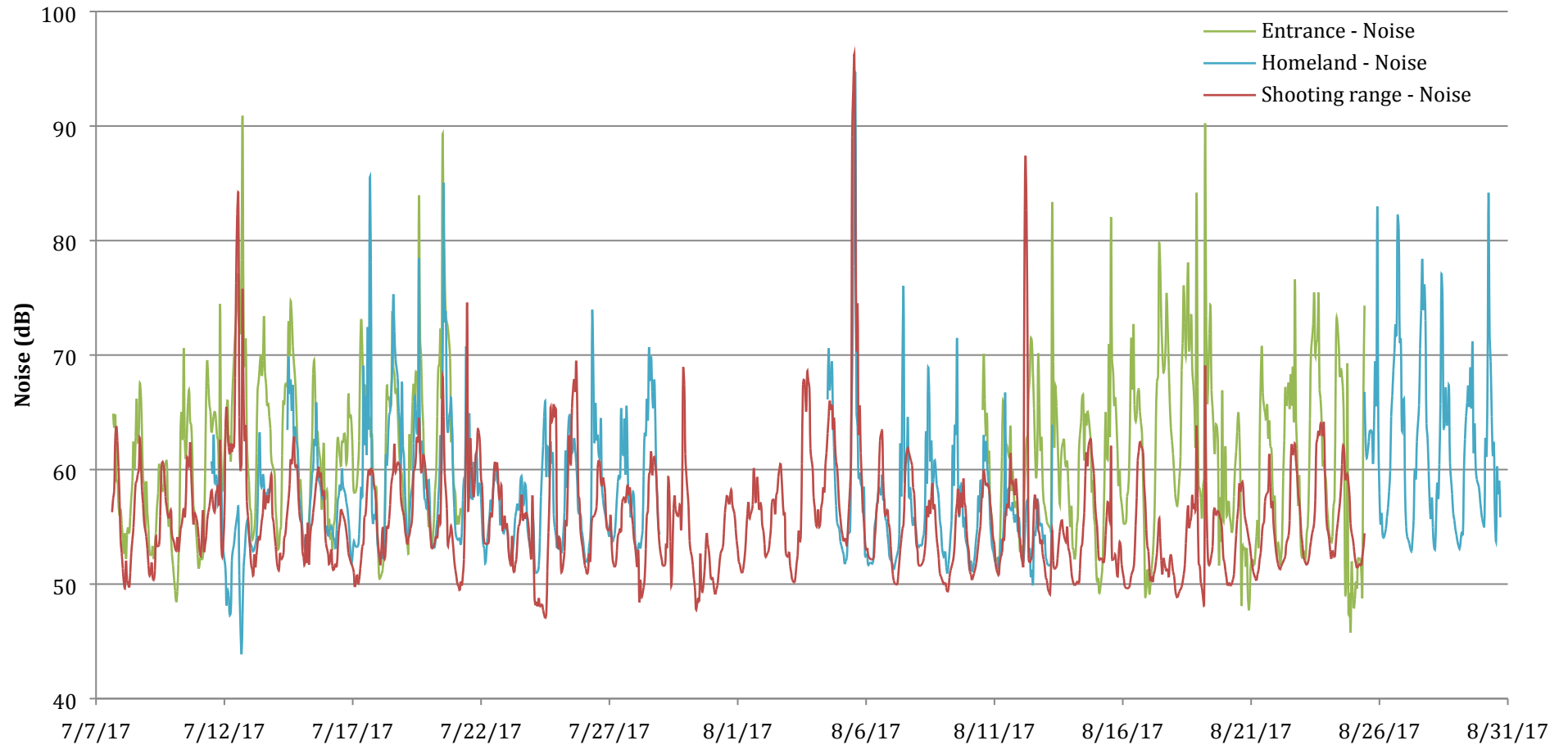
Comparison of Marineterrein with other areas

Marineterrein has lower levels of air and noise pollution compared to most areas in Amsterdam Centrum. Thus, having a quantifiable way to show this and compare with other real estates would be beneficial for Marineterrein. This could help to demonstrate to all the businesses present on the Marineterrein the quality of the environment they are part of.

Increased and optimised sensing infrastructure

The most influential sources of noise and air pollution in Marineterrein are now identified. Therefore, by adding and using targeted and localised sensors, it is possible to further increase and quantify the knowledge of noise and air pollution and its impacts in order to prepare actions to mitigate them.
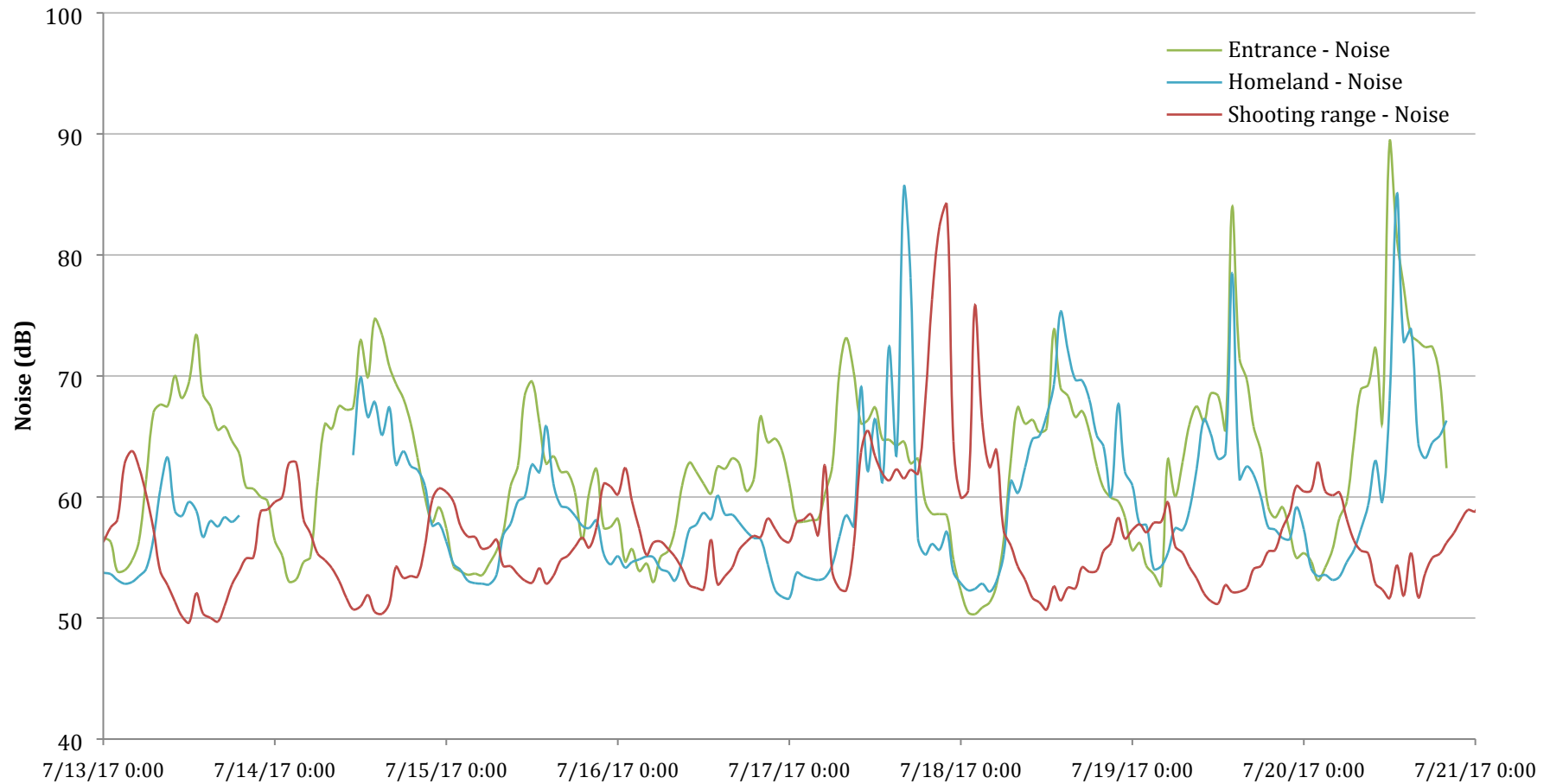
Appendix A.1 – Overview of noise pollution across the Marineterrein

This graph represents the overview of noise pollution at the Entrance, Homeland and Shooting range throughout the project.
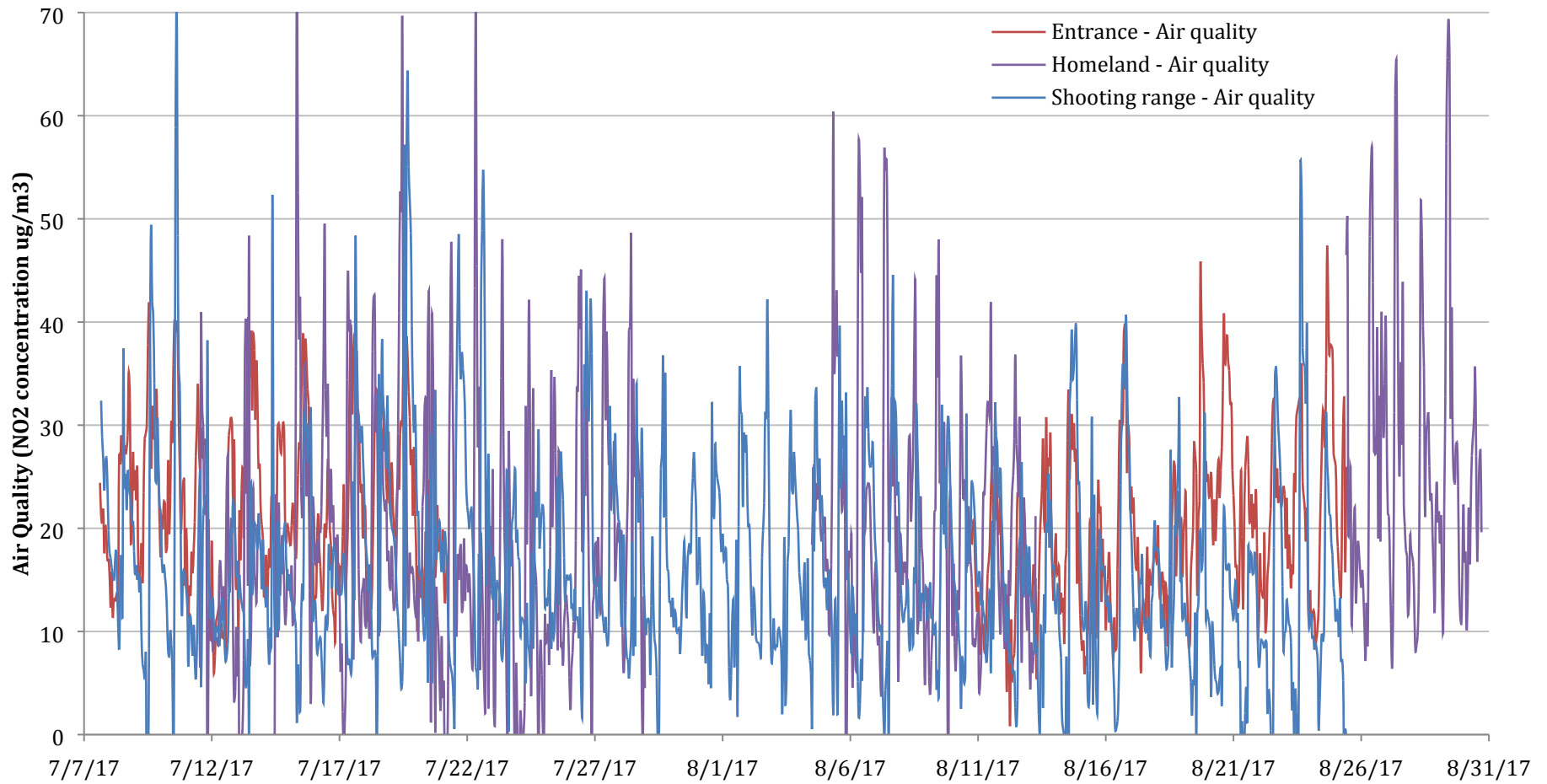
Appendix A.2 – In-depth noise pollution across the Marineterrein

This graph represents the in-depth noise pollution at the Entrance, Homeland and Shooting range across one week.
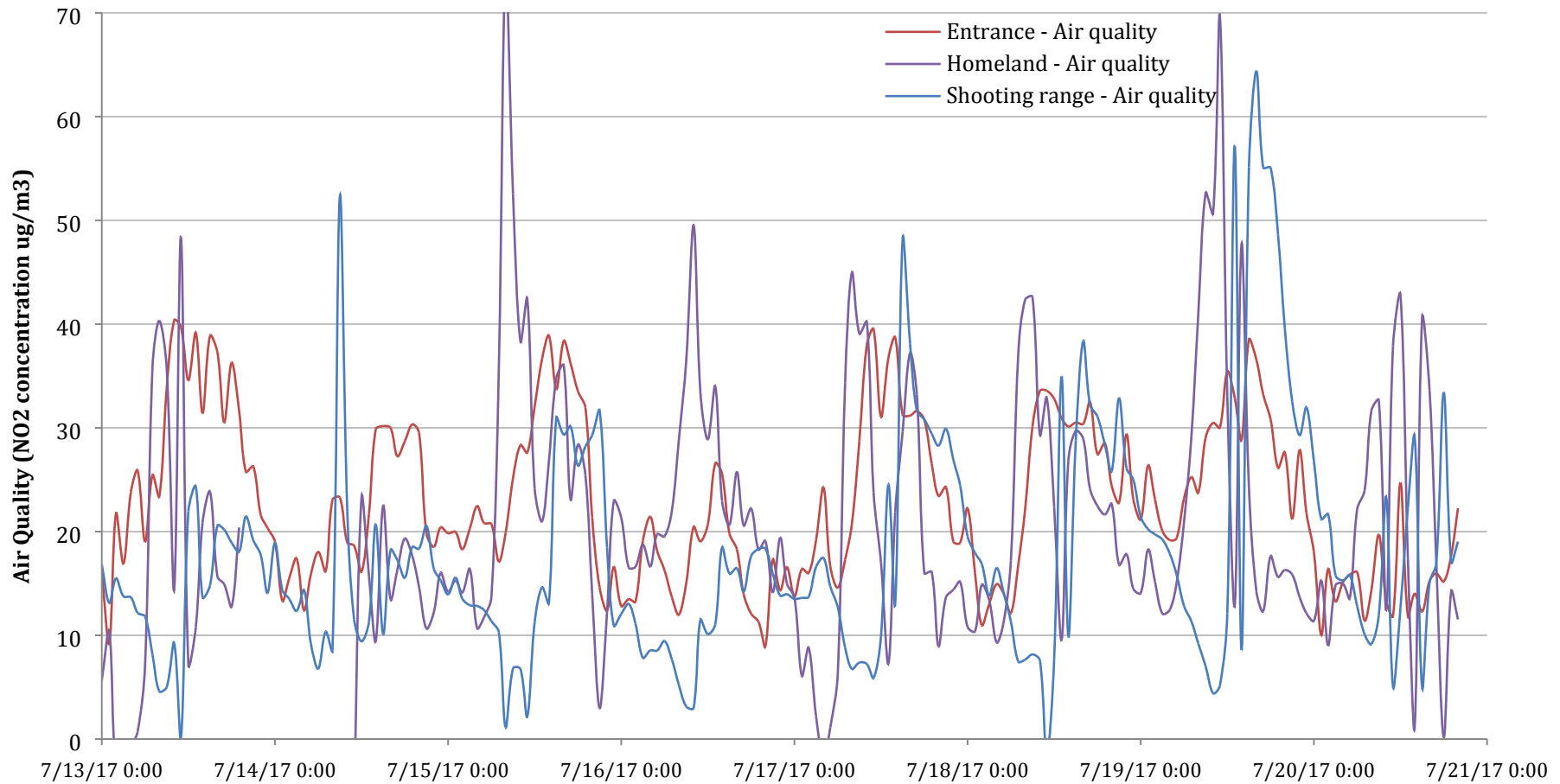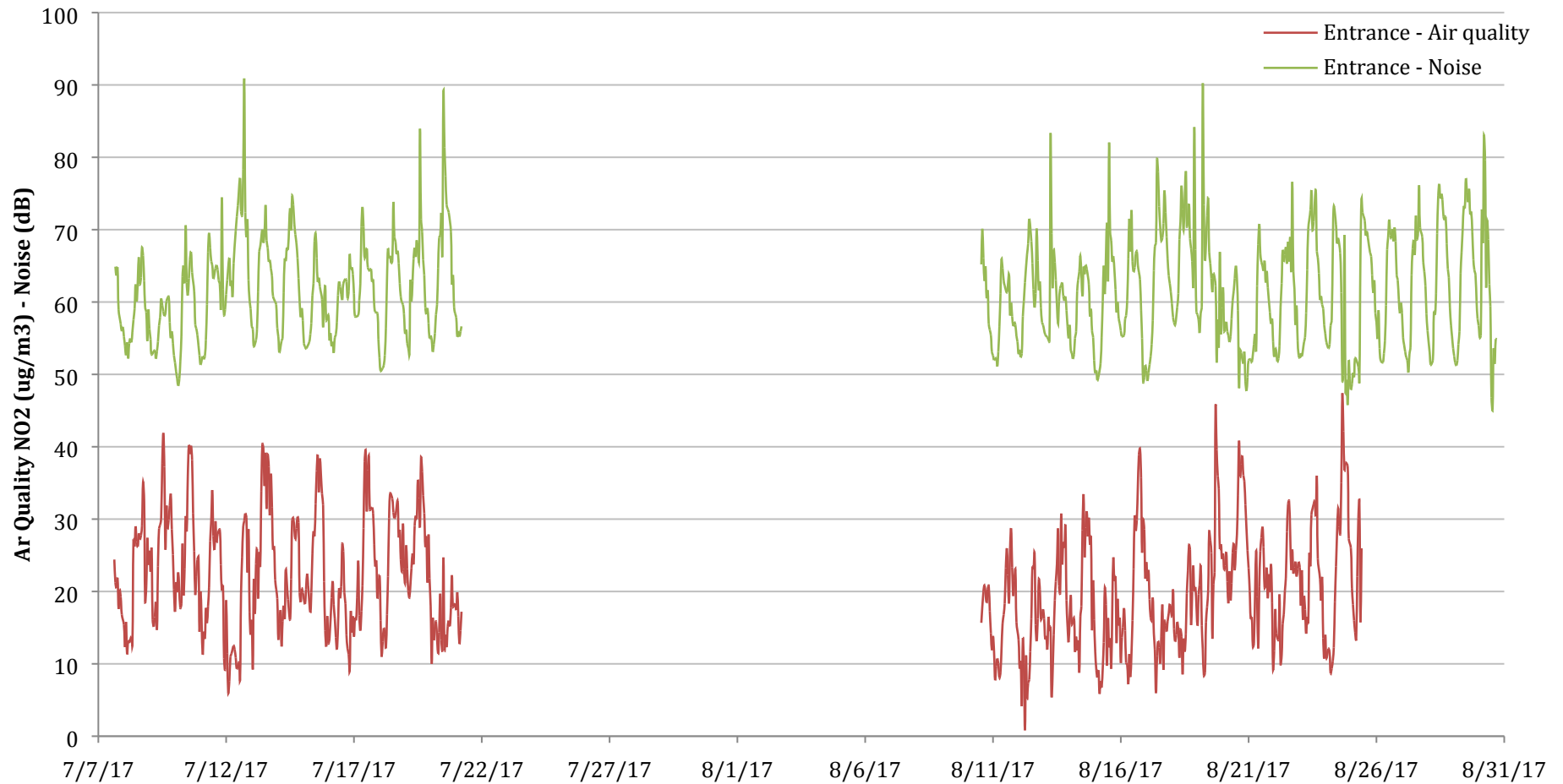
Appendix B.1 – Overview of air pollution across the Marineterrein

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Appendix B.2 – In-depth air pollution across the Marineterrein

This graph represents the in-depth air pollution at the Entrance, Homeland and Shooting range across one week.
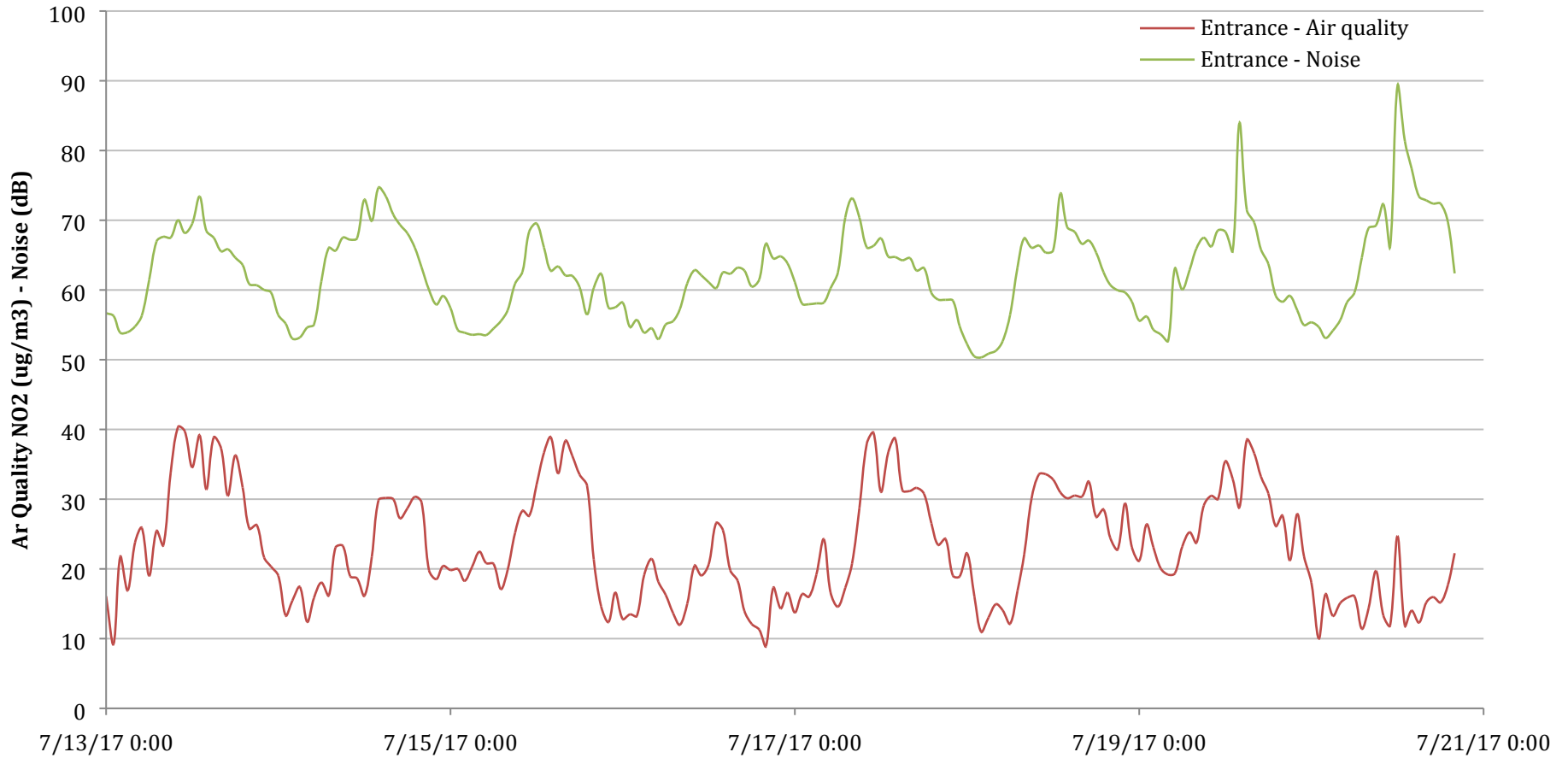
Appendix C.1 – Overview of noise and air pollution at the Entrance

This graph represents the overview of noise and air pollution data at the Entrance throughout the project.
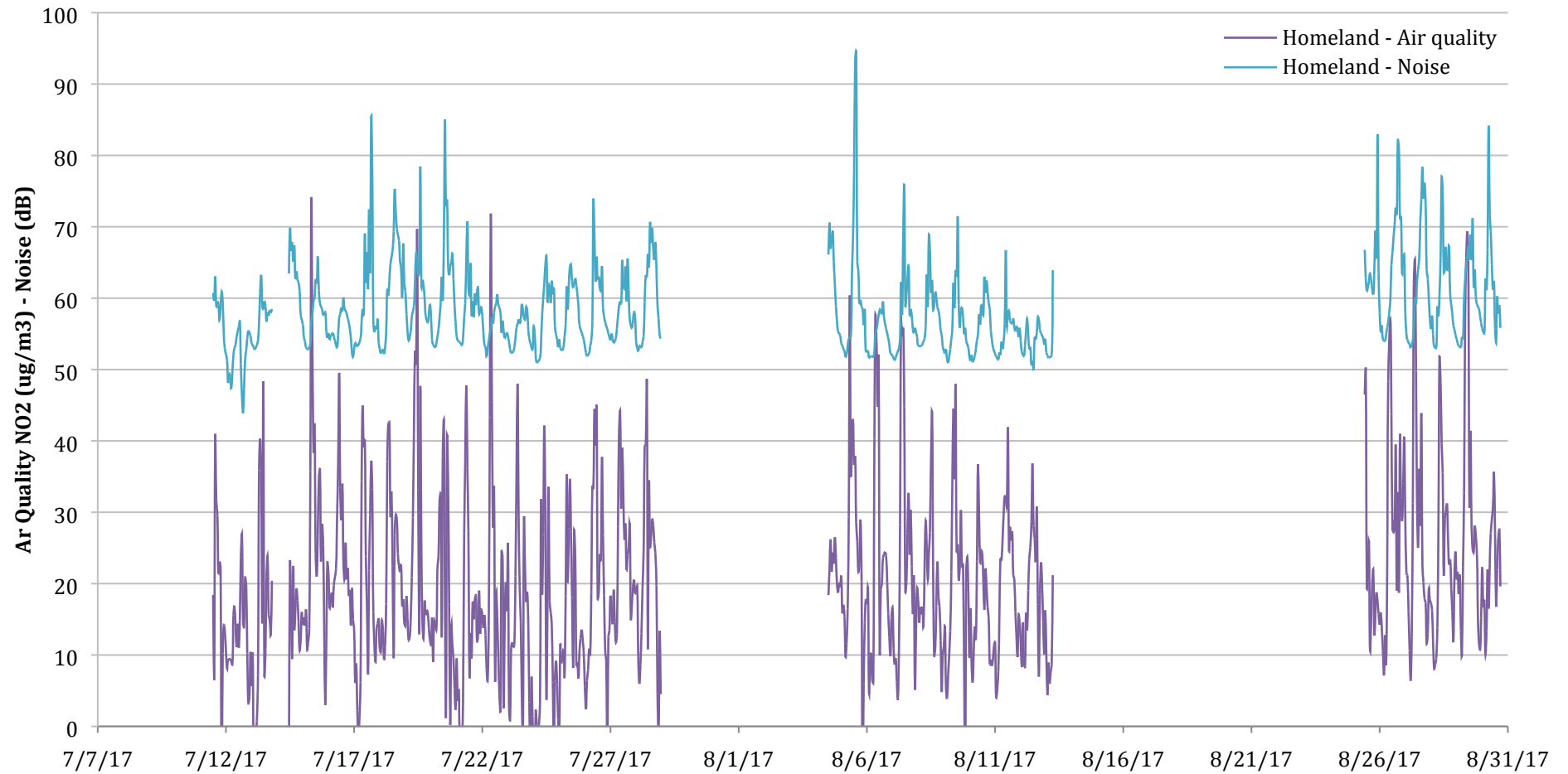
Appendix C.2 – In-depth noise and air pollution at the Shooting range

This graph represents the in-depth noise and air pollution data at the Entrance across one week.
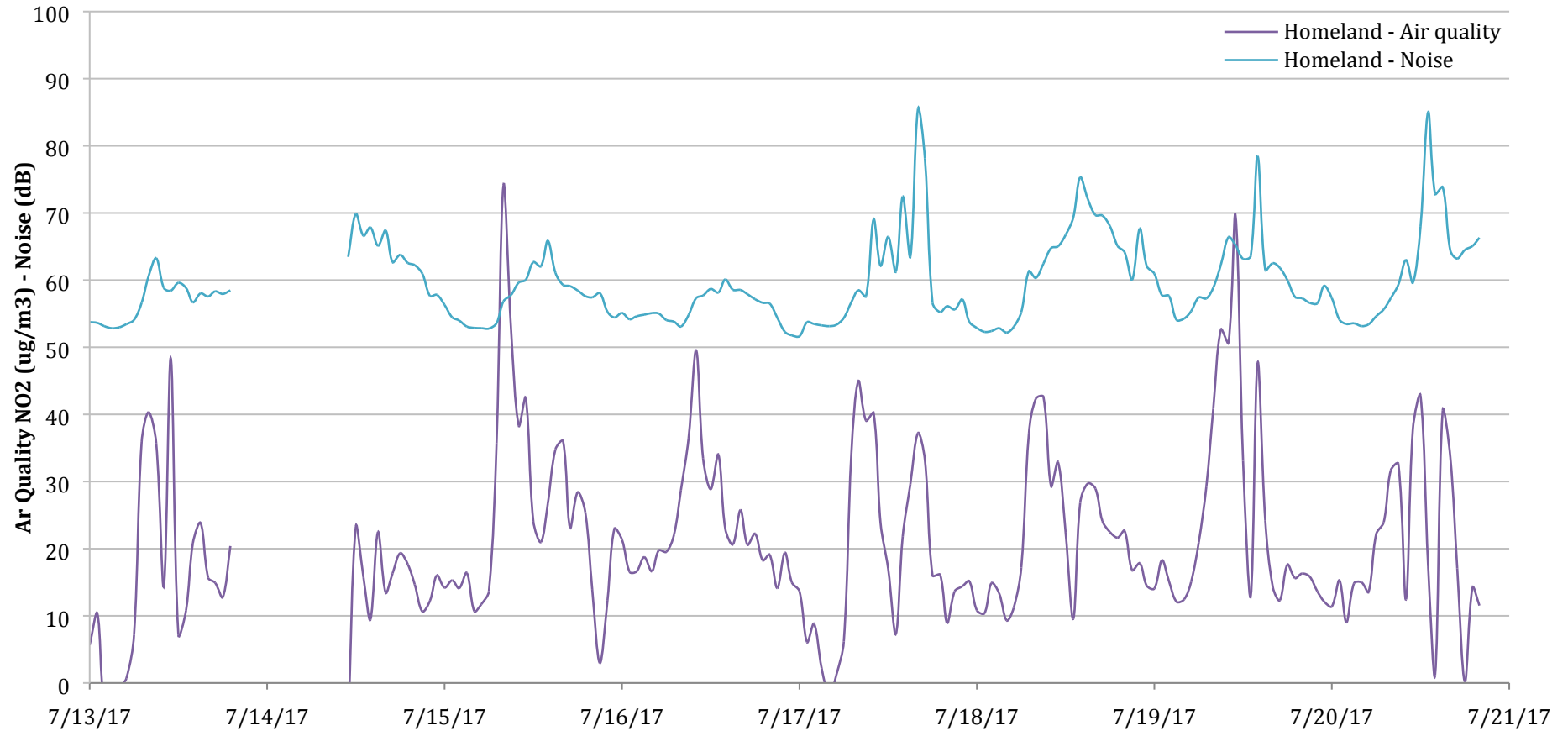
Appendix D.1 – Overview of noise and air pollution at Homeland

This graph represents the overview of noise and air pollution data at Homeland throughout the project.
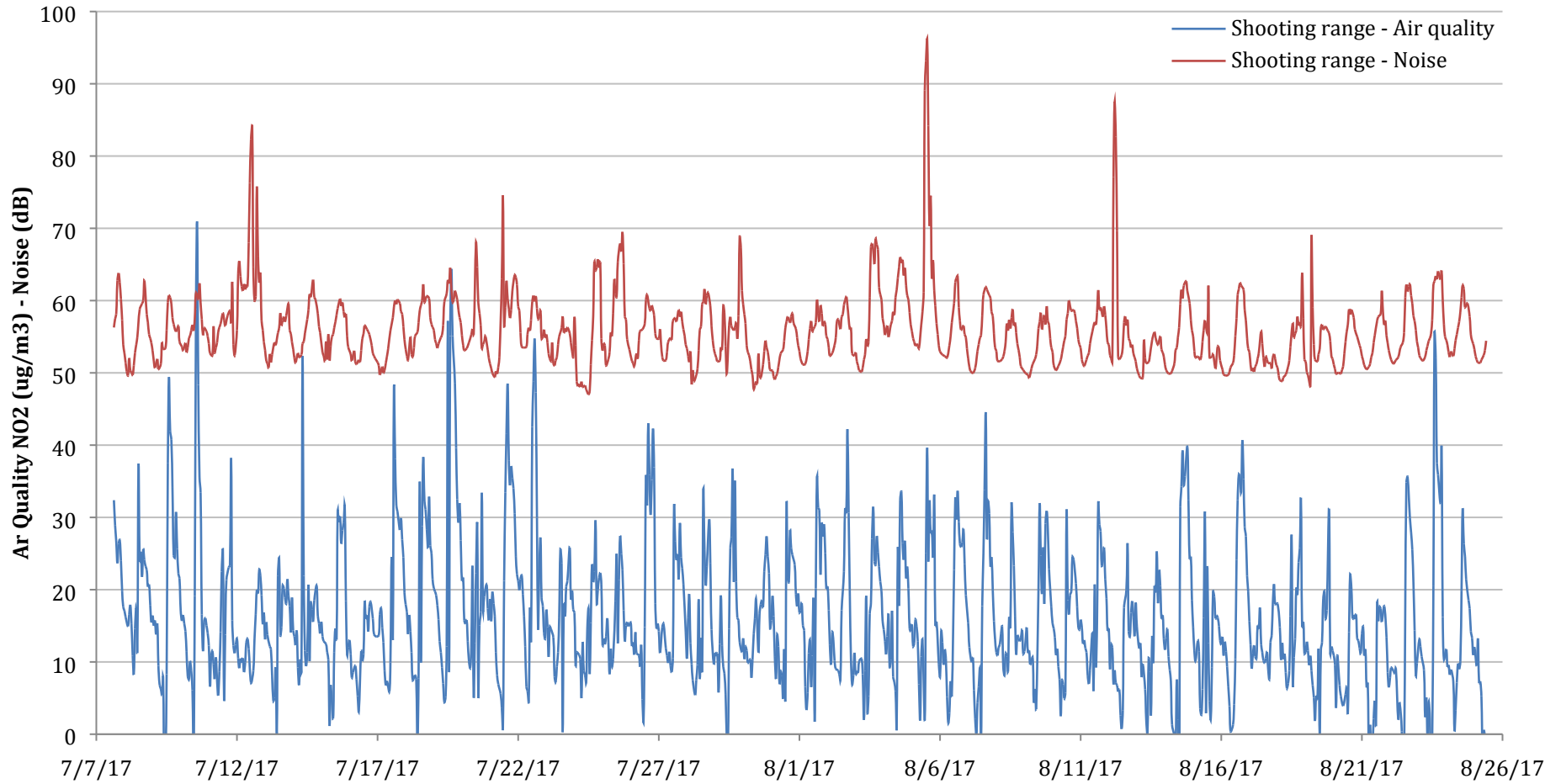
Appendix D.2 – In-depth noise and air pollution at Homeland

This graph represents the in-depth noise and air pollution data at Homeland across one week.

Appendix E.1 – Overview of noise and air pollution at the Shooting range

This graph represents the overview of noise and air pollution data at the Shooting range throughout the project.

Appendix E.2 – In-depth noise and air pollution at the Shooting range

This graph represents the in-depth noise and air pollution data at the Shooting range across one week.