Public Health Evaluation of Ambient Air Near a Shale Gas Well Site and School Campus:

Results from Long-term Air Monitoring at the Yonker Well Site Nearby the Fort Cherry School Campus in Washington County, PA

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Highlights

- This air quality and public health evaluation of December 2016 to October 2018 ambient air quality data collected at three sites in proximity to the Yonker well pad in Mount Pleasant Township showed that measured $PM_{2.5}$ and VOC concentrations were consistently below health-based air comparison values and thus are not expected to pose acute or chronic health concerns.
- The monitoring data for two of the air monitoring sites located between the Yonker well pad and the Fort Cherry School District campus indicate an absence of air quality impacts of potential health concern at the Fort Cherry School District campus associated with Yonker well pad air emissions.
- The measured $PM_{2.5}$ and VOC concentrations do not provide evidence of elevated long-term average concentrations relative to other parts of Washington County that are more distant from local natural gas development. The measured concentrations reflect the cumulative contributions of both air emissions from the Yonker well pad as well as from other local and regional air emission sources such as area well pad sites, and include concentrations during all phases of well pad construction and operation.
- A wind direction analysis showed that winds which would blow Yonker well pad air emissions towards the Fort Cherry School District campus (*i.e.*, winds from the south and southeast) were intermittent and relatively infrequent.

At the request of Range Resources – Appalachia, LLC (hereafter referred to as Range Resources), Gradient conducted an air quality and public health evaluation of ambient air measurement data collected between December 2016 and October 2018 at three monitoring sites in close proximity to the Yonker well pad in Mount Pleasant Township, Washington County, PA. Beginning in December 2016, AECOM Technical Services, Inc. (AECOM) initiated an air monitoring program on behalf of Range Resources. The program consisted of monitoring at three sites between approximately 1,000 to 2,800 feet from the Yonker well pad to characterize local air quality during different phases of well pad development, including well pad construction, vertical air drilling, horizontal drilling, hydraulic fracturing, flowback, and production. Given that the primary objective of the air monitoring study was to identify any air quality impacts of potential health concern at the Fort Cherry School District campus that may be associated with operations at the Yonker well pad, two of the air monitoring sites (Sites 1 and 2) were located to the northwest of the Yonker well pad between the well pad and the school campus. The third site (Site 3) was located to the southwest of the well pad – *i.e.*, upwind of the well pad for winds blowing in the direction of the school – in order to provide information as to whether other local sources, including the large number of unconventional natural gas wells in the area (see Figure ES.1 for a visual of the Yonker well pad, Figure 1.1 for a visual of nearby natural gas wells, and Figure 2.1 for a map of the three Yonker air monitoring sites), may contribute to air quality at the school. Fine particulate matter ($PM_{2.5}$) was continuously measured at Site 1 beginning in February 2017, while 24-hour canister air samples were collected every sixth day for measurement of 58 volatile organic compound (VOC) species at each of the three sites (beginning in December 2016 at Sites 2 and 3, and in February 2017 at Site 1). In addition, hourly wind speed and direction measurements were made at Sites 1 and 2, and additional meteorological parameters (*e.g.*, relative humidity, barometric pressure, and temperature) were also collected at Site 1. All measurements were collected using methods recommended by the US Environmental Protection Agency (US EPA).

For the air quality analysis, we calculated summary statistics and assessed differences in $PM_{2.5}$ and VOC concentrations between the sites and the different well pad activity periods. In addition, we analyzed wind speed and direction data to understand predominant wind directions and to characterize the frequency of time when winds were blowing in the direction of the monitoring sites from the well pad. The centerpiece of the public health evaluation was the comparison of short-term (24-hour) and long-term (>1 year) average $PM_{2.5}$ and VOC concentrations to acute and chronic health-based air comparison values developed by public health agencies to serve as conservative, health-protective benchmarks. In addition, we compared the Yonker $PM_{2.5}$ and VOC measurements to air concentrations measured at Pennsylvania Department of Environmental Protection (PADEP) monitoring sites in Washington County that are more distant from local oil and gas development activities and can be assumed to be representative of regional background air quality that is not significantly impacted by local oil and gas development activities. These comparisons were made in order to provide insight as to whether air emission sources at the Yonker well pad (as well as at other nearby well pad sites in Mount Pleasant Township) are significant contributors to the measured air pollutant concentrations, or whether $PM_{2.5}$ and VOC measurements for the Yonker air monitoring sites are instead consistent with regional air quality measurements.

Overall, we found an absence of $PM_{2.5}$ and VOC concentrations of either acute or chronic health concern, based on the comparison of valid measurements taken at the three Yonker air monitoring sites to health-based air comparison values. Further, our wind direction analysis showed that winds that would blow Yonker well pad emissions towards the Fort Cherry School District campus (*i.e.*, winds from the south and southeast) were intermittent and relatively infrequent, and therefore do not often transport emissions from the Yonker well pad towards the school campus. While winds in the direction of the monitoring sites from the Yonker well pad were relatively infrequent, there is extensive local Marcellus Shale development in the area, meaning that the monitoring data also provide insights on the nature of air quality related to other local unconventional natural gas development sites near the Fort Cherry School District campus. However, as discussed more below, the $PM_{2.5}$ and VOC data do not provide evidence of elevated long-term average concentrations relative to other parts of Washington County that are more distant from local natural gas development.

For the $PM_{2.5}$ measurements at Yonker air monitoring Site 1, we found no exceedances of the acute or chronic health-based air comparison values, and observed relatively minor differences in average concentrations between the different well activity phases and between the activity phases and periods of lesser activity that occurred between the activity phases (termed interlude periods). Our comparisons of the Yonker air monitoring Site 1 $PM_{2.5}$ data with $PM_{2.5}$ data from the PADEP Florence background site in Washington County showed similarities in both measured levels as well as temporal variation. Based on these data similarities and the predominant wind direction measured at Yonker air monitoring Site 1 (*i.e.*, winds blowing from the southwest), it is likely that the mean $PM_{2.5}$ measurements are associated with regional air quality rather than the Yonker well pad.

No exceedances of either acute or chronic health-based air comparison values were observed for any of the measured VOCs except acrolein; however, the acrolein data are considered to be unreliable given well-documented problems associated with the use of the VOC analytical method (Method TO-15) to measure acrolein (see Section 2.1.2). These comparisons thus do not provide evidence of measured VOC concentrations of public health concern at any of the three measurement sites, including the two sites representative of air quality in the direction of the Fort Cherry School District campus. The majority of the mean VOC concentrations for the Yonker air monitoring sites were below or similar to the values measured at the PADEP Washington County background sites, indicating that Yonker well pad emissions were not generally contributing to elevated long-term average VOC concentrations. For some VOCs (*e.g.*, for acetone, methylene chloride, n-hexane, propylene, and toluene), maximum 24-hour measurements at one or more of the Yonker air monitoring sites were substantially higher than the maximum measured background concentrations. Our analysis of wind direction data for the measurement periods of the maximum concentrations indicate that the Yonker well pad was a possible contributing source to some, but not all, of these maximum concentrations and that other sources unrelated to the well pad were likely more significant contributors for the majority of the maximum concentrations.

We conducted a further evaluation of a subset of VOCs that have been more commonly associated with oil and gas activity (benzene, ethylbenzene, n-heptane, n-hexane, toluene, m,p-xylenes, o-xylene, propylene, ethanol, and methanol). For these VOCs, we observed some variability in concentrations between the three sites and between the different well pad activity phases, although as detailed above, the measured concentrations of these VOCs were consistently below health-based air comparison values. For Site 1, maximum detected 24-hour concentrations of these VOCs were most frequently observed during the horizontal drilling phase at the Yonker well pad, while at Site 2, the maximum concentrations were most frequently observed during the flowback and production phases. Together, these data for air monitoring conducted at Sites 1 and 2, which would capture any air emissions from the Yonker well pad blown in the direction of the Fort Cherry School District campus, do not show VOC concentrations of public health concern in the direction of the school campus. The maximum detected 24-hour concentrations of these VOCs at Site 3 were most frequently observed during the interludes between well pad activity phases, indicating that the concentrations may reflect the impacts of other local and regional sources.

Figure ES.1 Aerial Photograph of the Yonker Well Pad.

1 Introduction

1.1 Background on Oil and Gas Development Activities in Mount Pleasant Township

The Yonker well pad is located on farmland in Mount Pleasant Township, in Washington County, PA, less than one mile south of the Fort Cherry High School. It is located near the eastern periphery of a portion of Washington County with extensive oil and gas development (OGD) activity. It is estimated that 95% of Mount Pleasant Township is under lease agreement (Gable, 2016). Based on well pad information available in the Pennsylvania Department of Environmental Protection (PADEP) PA Oil and Gas Mapping tool (PADEP, 2019), there are more than 40 additional unconventional natural gas well pad sites within five miles of the Yonker well pad site, totaling more than 160 active unconventional natural gas wells. Other potential OGD-related air emissions sources within five miles of the Yonker well pad include natural gas pipelines and associated pigging operations, and several compressor stations, including the Brigich Compressor Station in Houston, PA.

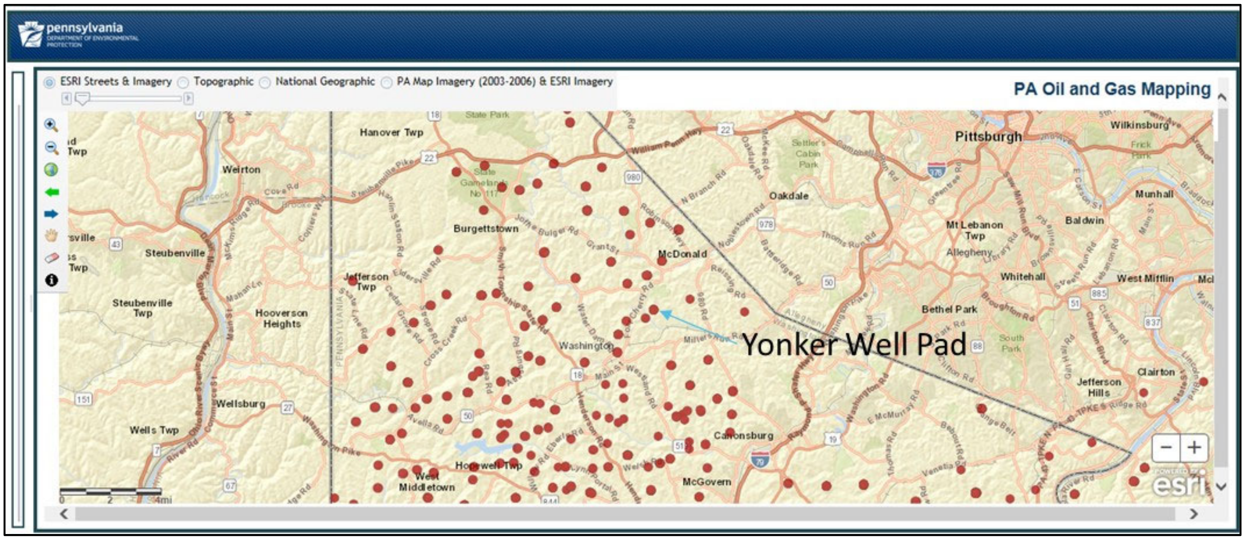

Figure 1.1 Location of the Yonker Well Pad Relative to Active Unconventional Natural Gas Wells. The location of the Yonker well pad is indicated by a light blue arrow, and red circles indicate the locations of active unconventional natural gas well pad sites. Source: PADEP, 2019.

1.2 Overview of Well Pad Development Activities at the Yonker Well Pad

Well pad construction at the Yonker well pad began in October 2016, and all wells were in production as of October 24, 2017. More specifically, the following timeline summarizes well pad activities at the Yonker well pad:

- Prior to Jan. 5, 2017: site construction and set-up;
- Jan. 5-Feb. 18, 2017: vertical air drilling;

- Mar. 3-May 7, 2017: horizontal drilling;
- June 18-Aug. 13, 2017: hydraulic fracturing;
- Sept. 8-Oct. 23, 2017: flowback; and
- After Oct. 23, 2017: all wells in production.

There were three extended periods of lesser activity in between the different well pad development phases that we've termed interlude periods:

- Feb. 19-Mar. 2, 2017: Interlude I;
- May 8-June 17, 2017: Interlude II; and
- Aug. 14-Sept. 7, 2017: Interlude III.

Notably, each of the six wells commenced flowback at a different date during the flowback period listed above, and therefore each well commenced production at a different time. However, all wells were in production after October 23, 2017.

1.3 Overview of the Yonker Well Pad Air Monitoring Program

The Yonker well pad air monitoring program was designed to measure air quality during all phases of well pad development and production in order to address community concerns about air quality at the nearby Fort Cherry School District campus. As such, monitoring began at two of the measurement sites (Sites 2 and 3) in December 2016 and at a third measurement site (Site 1) in February 2017. The air monitoring continued through October 31, 2018, to ensure that a full year of measurements was collected for all wells in production. The monitoring program was conducted by AECOM Technical Services, Inc. (AECOM) and consisted of continuous measurements of fine particulate matter ($PM_{2.5}$; particulate matter less than or equal to 2.5 microns in aerodynamic diameter), 24-hour measurements of 58 VOCs, and meteorological parameters including wind speed and direction. All measurements were collected using equipment and methods consistent with US EPA recommendations. Additional details on the air monitoring program are provided in Section 2.1.

1.4 Objective of the Public Health Evaluation

We conducted a public health evaluation of this air monitoring dataset by comparing measured air concentrations to conservative acute and chronic health-based air comparison values (HBACVs). The objective of this public health evaluation was to determine whether measured air concentrations for any target species are in excess of acute and chronic HBACVs. Exceedances of the HBACVs should not be interpreted as providing evidence of the likelihood of air-related public health impacts of emissions from the Yonker well pad. There are several reasons why this is the case, including that the HBACVs we relied upon are not bright lines above which health effects are expected; instead, due to the use of conservative (*i.e.*, health-protective) assumptions and safety and/or uncertainty factors, they typically specify exposure levels that are from several-hundred-fold to several-thousand-fold lower than the exposure level at which the actual adverse effect was observed in people or laboratory animals (US EPA, 2004). In addition, measured air concentrations will not be specific to just air emissions from the Yonker well pad, as the majority of the measured species have a large number of common anthropogenic and natural sources and are thus commonly measured in ambient air. Finally, as discussed in Section 2, monitoring Sites 1 and 2 are located in the direction of the Fort Cherry School District campus, but closer to the Yonker well pad, suggesting that the air quality measurements at these sites may be a conservative estimate of air quality at the school campus (because, in general, air concentrations of $PM_{2.5}$ and VOCs decrease with increased distance from the emission source). Given the location of two of the air monitoring sites between the Yonker well pad and the Fort Cherry School District campus (Yonker air monitoring Sites 1 and 2), it is reasonable to interpret the absence of any exceedances of HBACVs for measured concentrations at these two air monitoring sites as providing reliable evidence that air quality impacts of potential health concern at the Fort Cherry School District campus from Yonker well pad air emissions would be unlikely. Overall, any exceedances of HBACVs would warrant further assessment to determine whether the exceedances may be associated with air emission sources at the Yonker well pad or other local sources and to examine various factors (*e.g.*, frequency of exceedance, magnitude of exceedance, potential for exposure at the site or sites of the exceedances) that affect their potential health implications.

2 Study Design and Methods

2.1 Yonker Well Pad Air Monitoring Program Design and Methods

2.1.1 Air Sampling Locations and Dates

The air monitoring program consisted of three measurement sites located between approximately 1,000 to 2,800 feet away from the Yonker well pad (AECOM, 2019, Figure 2.1). Monitoring began at Sites 2 and 3 on December 15, 2016, and at Site 1 on February 8, 2017, and continued through October 31, 2018, at all three sites. The goal of the air measurements was to assess the air quality impacts of Yonker well pad emissions at the Fort Cherry School District campus, in response to community concerns. As such, Sites 1 and 2 were located northwest of the well pad, in the direction of the Fort Cherry School District campus. Site 1 was located as close to the school district campus as possible given the availability of local lands to be used as monitoring locations and is therefore most representative of air quality on the campus. Site 2 was located between Site 1 and the Yonker well pad, and the VOC and wind direction measurements at this site were intended to confirm the data collected at Site 1. Site 3 was located southwest of the Yonker well pad, and was intended to serve as a site that would measure air quality associated with sources besides the Yonker well pad, depending on the wind direction. All three sites were located on infrequently populated lands, with Sites 2 and 3 located on agricultural fields and Site 1 located on the grounds of the Fort Cherry Golf Club. The predominant wind direction near the Yonker well pad is from the west and southwest (Figures 2.2 and 2.3), indicating that the predominant downwind direction from the well pad is to the east and northeast. Plots of the wind direction by season at both sites demonstrated that there is little seasonal variability in the predominant wind direction. While the downwind direction would generally be considered a priority location for an air monitor, a monitoring site was not established to the northeast of the well pad because the area is wooded, inaccessible, and relatively unpopulated (AECOM, 2019) and because the primary goal of the air monitoring was to evaluate air quality at the Fort Cherry School District campus.

Figure 2.1 Location of the Yonker Well Pad Relative to the Air Monitoring Sites and Fort Cherry School District Campus. Source: AECOM, 2019.

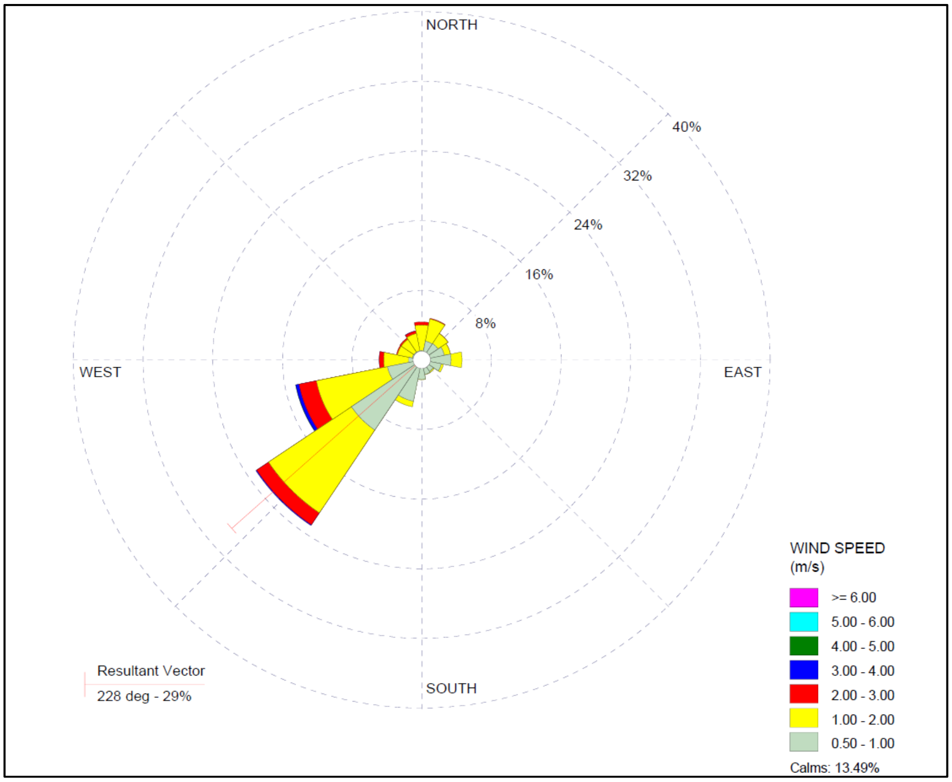

Figure 2.2 Wind Rose for Yonker Air Monitoring Site 1. The wind rose includes data collected between Feb. 8, 2017, and Oct. 31, 2018.

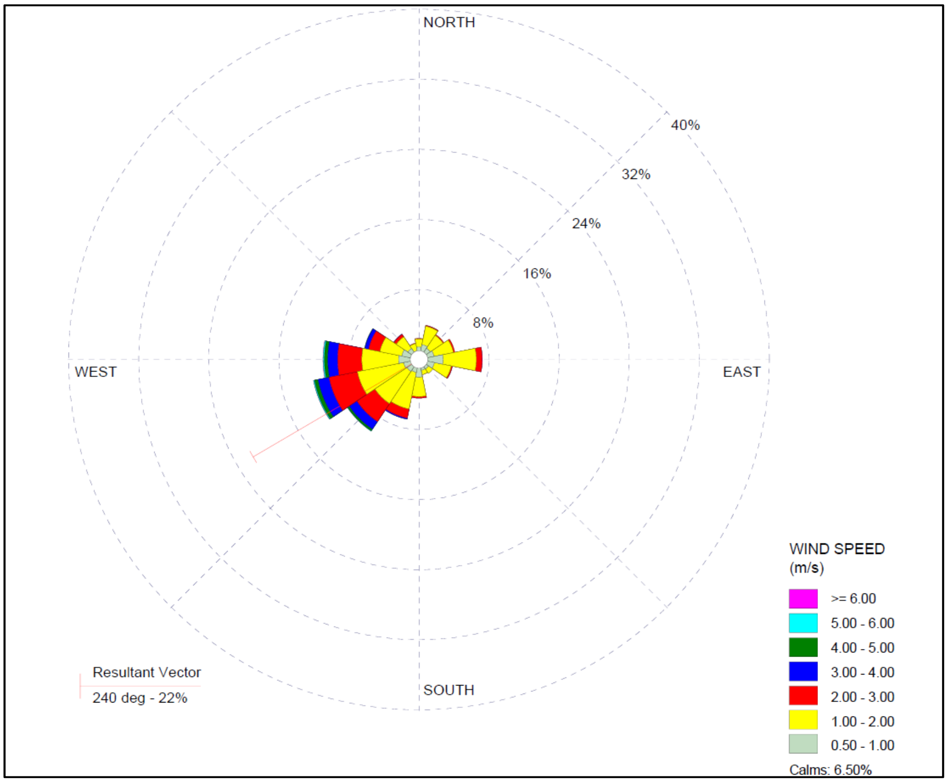

Figure 2.3 Wind Rose for Yonker Air Monitoring Site 2. The wind rose includes data collected between Dec. 16, 2016, and Oct. 31, 2018.

2.1.2 Volatile Organic Compound Measurements

VOC measurements were conducted at all three monitoring sites. The VOC measurements involved collection of 24-hour samples in stainless steel canisters every six days and subsequent laboratory analysis of the canister contents for VOCs using US EPA Method TO-15. In total, the laboratory analysis focused on 58 VOC species, including VOC species commonly associated with oil and gas sites such as benzene, toluene, ethylbenzene, and xylenes. The list of 58 VOC species was selected to match the set of TO-15 VOC species typically monitored by PADEP at its air toxics sampling sites across the state (AECOM, 2019).

Importantly, as discussed in PADEP (2010), PADEP has previously determined that acrolein measurements made *via* Method TO-15 are unreliable. The 2010 PADEP Southwestern Pennsylvania Marcellus Shale Short-Term Ambient Air Sampling Report (PADEP, 2010) provided acrolein measurement results but advised against their use "for any type of analysis." PADEP's determination of their unreliability was based on US EPA's findings related to acrolein measurements obtained using the same canister collection method during the US EPA School Air Toxics Monitoring Initiative. As discussed in a 2012 Fact Sheet issued as part of the US EPA School Air Toxics Monitoring Initiative (US EPA, 2012), US EPA concluded that acrolein data obtained *via* Method TO-15 are unreliable based on the erratic results from the schools monitoring project, as well as results from a short-term laboratory study where multiple labs analyzed samples containing a known level of acrolein and obtained highly variable results. As described in US EPA (2012), investigation into the discrepancies in the acrolein data identified several shortcomings to the current implementation of Method TO-15 that may affect accurate measurement of acrolein, including no requirement for heat cleaning of canisters (which is noted as "making results somewhat higher") and variability in the length of time between when canisters are prepared and when they are used and between when they are used and when they are analyzed. US EPA continued to report the acrolein results from the schools monitoring project, but given "significant questions about the consistency and reliability" of the results, concluded that "the monitoring methods in place at that time did not provide data of sufficient quality for us to evaluate the potential for health concerns from acrolein exposures at individual schools" (US EPA, 2012). Notably, Method TO-15 is considered robust for the other VOCs measured; US EPA has stated that acrolein is difficult to measure *via* this method due to its reactivity, which leads to the formation of "other compounds that complicate laboratory analysis," and because "other chemical compounds can react to form acrolein, potentially even within the canisters used for collecting air samples" (US EPA, 2012).

2.1.3 $PM_{2.5}$ Measurements

Yonker air monitoring Site 1 was selected for $PM_{2.5}$ measurements because it was in closest proximity to the Fort Cherry School District campus. AC power – which is needed to operate US EPA-recommended particulate matter instruments – was not originally available at any of the sites, but Range Resources installed AC power at Yonker air monitoring Site 1 so that $PM_{2.5}$ could be measured. Hourly average $PM_{2.5}$ measurements were collected continuously using a Met One Instruments Model BAM-1020, which is a US EPA Federal Equivalent Method (FEM).

2.1.4 Meteorological Parameter Measurements

Wind speed and direction were collected at Sites 1 and 2, and additional meteorological parameters (*e.g.*, relative humidity, barometric pressure, and temperature) were collected at Site 1 (AECOM, 2019). Hourly average meteorological parameter measurements were collected continuously using solar powered monitoring equipment.

2.2 Statistical Data Analysis

2.2.1 Air Pollutant Summary Statistics

Summary statistics were calculated for the $PM_{2.5}$ measurements at Site 1 for each of the well pad development periods listed in Section 1.2 and for the interludes between these periods (*i.e.*, the dates between vertical air drilling, which ended on February 18, 2017, and horizontal drilling, which started on March 3, 2017; between horizontal drilling, which ended on May 7, 2017, and hydraulic fracturing, which started on June 18, 2017; and between hydraulic fracturing, which ended on August 13, 2017, and flowback, which started on September 8, 2017). More specifically, the following statistics were calculated: the mean and standard deviation of the hourly measurements during each period, the maximum 24-hour measurement during each period, and the total number of days in each period with 24-hour measurements.

For VOCs, we calculated summary statistics for each of the three Yonker air monitoring sites, including mean, standard deviation, and maximum 24-hour concentrations. We focused on a subset of 10 VOCs that were more frequently detected and that have been associated with oil and gas activity (benzene, ethylbenzene, n-heptane, n-hexane, toluene, m,p-xylenes, o-xylene, propylene, ethanol, and methanol) in order to characterize any differences in pollutant concentrations between the air monitoring sites and the well pad activity periods.

2.2.2 Meteorological Data Analysis

The wind direction data collected at Yonker air monitoring Sites 1 and 2 were evaluated in two ways. First, for each site and well pad activity period, the average daily wind direction was calculated. These wind directions were categorized into eight categories representing winds arriving from the north (N), northeast (NE), east (E), southeast (SE), south (S), southwest (SW), west (W), and northwest (NW), and the percent of days in which the winds arrived from each of these directions was calculated. This categorization of the data allowed for evaluation of the wind direction on a daily basis, which is the averaging period for the Yonker VOC data. Second, for each site and activity period, the percent of hourly wind measurements in each of the eight wind directions was calculated. This calculation provided a more holistic evaluation of the hourly wind direction measurements and can be used to understand general wind direction trends near the Yonker well pad.

2.3 Methodology for Public Health Evaluation

2.3.1 Screening-level Evaluation of VOCs and $PM_{2.5}$

The air quality data from the three air monitoring sites were compared to acute and chronic HBACVs. The HBACVs selected for this evaluation are conservative (health-protective) benchmarks developed by public health agencies that best match the averaging times of the Yonker well pad data.

2.3.1.1 Evaluation of $PM_{2.5}$

The US EPA $PM_{2.5}$ primary National Ambient Air Quality Standards (NAAQS) were used as $PM_{2.5}$ acute and chronic benchmarks. The primary NAAQS are developed to be protective of public health, including the health of sensitive populations such as asthmatics, children, and the elderly. There are currently two primary $PM_{2.5}$ NAAQS: a 24-hour standard and an annual standard.

The 24-hour NAAQS requires that air concentrations remain below 35 $\mu g/m^3$, when considering a three-year average of the 98th percentile of 24-hour measurements at a given site. To facilitate comparison with the NAAQS, the hourly Yonker air monitoring Site 1 data were averaged over 24-hour periods (for any period in which at least 18 1-hour measurements were recorded). Then, the maximum 24-hour average concentration from Yonker air monitoring Site 1 was compared to the level of the NAAQS (35 $\mu g/m^3$), which is a conservative comparison given that the standard is intended to be compared to a 98th percentile value.

The annual $PM_{2.5}$ NAAQS requires that the annual mean $PM_{2.5}$ measurement at a given site, averaged over three years, remain below 12.0 $\mu g/m^3$. Given that $PM_{2.5}$ measurements at Yonker air monitoring Site 1 were only available between February 2017 and October 2018 (*i.e.*, were not available for a three-year period), the mean concentration from this entire time period was calculated and compared to the annual NAAQS.

2.3.1.2 Evaluation of VOCs

The public health evaluation of acute health risks posed by VOCs involved comparison of the maximum 24-hour measurement of each VOC detected at the three Yonker air monitoring sites with acute HBACVs. A tiered approach was used to identify acute HBACVs for use in this evaluation because there was not a single source of HBACVs for all VOCs under evaluation. Agency for Toxic Substances and Disease

Registry (ATSDR) acute inhalation Minimal Risk Levels (MRLs) were considered to be the preferred source of HBACVs (ATSDR, 2018a) because they are specifically developed to be protective of 24-hour exposure durations according to a well-documented, conservative (*i.e.*, health-protective) process. They are generally based on the most sensitive substance-induced end point considered to be of relevance to humans (ATSDR, 2017b). ATSDR further defines MRLs as being set "below levels that, based on current information, might cause adverse health effects in the people most sensitive to such substance-induced effects" (ATSDR, 2018b). ATSDR acute inhalation MRLs are derived for 1-14 day exposure durations; therefore, given that adverse health effects are generally observed at lower concentrations over longer exposure durations, comparison with the 24-hour Yonker air monitoring site measurements is conservative.

If an ATSDR acute inhalation MRL was not available for a VOC, acute inhalation reference concentrations (RfCs) from the Department of Energy Oak Ridge National Laboratory (ORNL) Risk Assessment Information System (RAIS) were used (Oak Ridge National Laboratory, 2018). While the ATSDR acute MRLs are a primary source of acute inhalation RfCs in the RAIS, it also contains other well-documented acute inhalation exposure guidelines, including the California Environmental Protection Agency (CalEPA) Office of Environmental Health Hazard Assessment (OEHHA) reference exposure levels that are developed for 1-hour and 8-hour acute exposure durations. The RAIS RfCs have been adopted by PADEP as health-protective concentrations representing time periods of one day or less in public health evaluations (*e.g.*, PADEP, 2010). If ATSDR MRLs and RAIS RfCs were not available for a VOC, we derived an acute HBACV by multiplying a US EPA chronic RfC (US EPA, 2018) by 10. We multiplied chronic RfCs by 10 because chronic RfCs are designed for long-term exposures which will typically elicit adverse chronic health responses at levels well below those that elicit acute responses. This methodology of using the chronic RfCs multiplied by 10 has been employed by US EPA in past risk evaluations when acute HBACVs are not available for given substances (*e.g.*, US EPA, 2009).

For twelve of the VOCs measured, no acute HBACV was available from the sources listed above. Notably, the TO-15 method used to measure VOCs in the air samples collected at the three Yonker air monitoring sites includes many VOCs that are not commonly associated with oil and gas activity. Eleven of the VOCs for which no acute HBACV was available are among the VOCs measured by the TO-15 method that are not commonly associated with oil and gas activity, and they were either not detected in any air samples, were infrequently detected, or were detected at very low, sub-part per billion (ppb) levels. For the twelfth VOC, ethanol, the US National Institute for Occupational Safety and Health (NIOSH) time-weighted average recommended exposure limit (REL) was selected as the acute HBACV. This REL is intended to be protective of worker health for up to a 10-hour work day during a 40-hour work week over a working lifetime (NIOSH, 2016). Notably, this REL is equivalent to the US Occupational Safety and Health Administration (OSHA) permissible exposure limit (PEL) and the American Conference of Governmental Industrial Hygienists (ACGIH) 15-minute threshold limit value–short-term exposure limit (TLV-TWA) for ethanol. While the NIOSH REL is an occupational exposure limit, and therefore does not directly apply to ambient air exposures, it is a reasonable value to use in this evaluation given the low toxicity of ethanol.

The public health evaluation of chronic health risks posed by VOCs involved comparison of the mean VOC measurements at each site to non-cancer US EPA RfCs and estimated continuous lifetime exposure concentrations associated with a 1-in-10,000 excess lifetime cancer risk (US EPA, 2018). Mean VOC concentrations for each Yonker air monitoring site were calculated for any VOC for which there was at least one detection at the site. In these calculations, half of the detection limit was substituted for any measurements below the detection limit before calculating the mean. For non-carcinogenic VOCs, the mean concentrations were compared to US EPA non-cancer RfCs, and for known or suspected human carcinogens, the mean concentrations were compared to the lower value of either the non-cancer US EPA RfC or the cancer-based estimated continuous lifetime concentrations. Using US EPA inhalation unit risk (IUR) estimates, we calculated the cancer-based estimated continuous lifetime concentrations for a 1-in-10,000 excess lifetime cancer risk, consistent with the US EPA residual risk program and with long-term comparison levels developed as part of US EPA's School Air Toxics Initiative (US EPA, 2009). The chronic HBACVs used in this evaluation are most appropriate for comparison to lifetime exposures to a VOC, so it is conservative to compare these values to the mean VOC concentrations at the Yonker air monitoring sites (which are based on measurements made over approximate 20- to 22-month periods).

2.3.2 Comparison of Yonker VOC and $PM_{2.5}$ Measurements to Regional Air Quality Measurements

In addition to the screening-level evaluations with acute and chronic HBACVs described above, the Yonker $PM_{2.5}$ and VOC measurements were also compared to measured air concentrations for monitoring sites in Washington County that are more distant from local oil and gas development activities and that are assumed to represent regional background air quality in Washington County. These comparisons were made in order to provide insight as to whether air emission sources at the Yonker air monitoring site (as well as at other nearby well pad sites) may be significant contributors to the measured air pollutant concentrations, or whether $PM_{2.5}$ and VOC measurements for the Yonker monitoring sites are instead consistent with regional air quality measurements.

The Yonker $PM_{2.5}$ measurements were compared to measurements from the Florence air monitoring site in Washington County, which is maintained by PADEP "for purposes of regional background and transport monitoring" (PADEP, 2017). Five years of recent $PM_{2.5}$ measurements (2013-2017) were used to calculate the following statistics for the Florence site: the maximum 1-hour and 24-hour $PM_{2.5}$ concentrations for each year, the annual mean $PM_{2.5}$ concentration, and the standard deviation of the mean for each year. $PM_{2.5}$ data from 2018 were not used because a full year of data were not available through the US EPA Air Quality System (AQS) website.

The Yonker VOC measurements were compared to measurements from the PADEP Florence and Charleroi air monitoring sites in Washington County. PADEP has identified the Florence site as an air monitoring site representative of background air quality in Washington County (PADEP, 2010, 2018); for this evaluation, over a year of data from the time period between October 2012 and December 2013 were obtained from the PADEP "Long-term Ambient Air Monitoring Project: Marcellus Shale Gas Facilities" (PADEP, 2018) where 24-hour canister samples were collected every sixth day for VOC analysis. The Charleroi monitoring site, which has been in use since 1974, is not immediately adjacent to oil and gas sources and is considered by PADEP to be a neighborhood-scale monitoring site (PADEP, 2017). For the Charleroi monitor, VOC data are available on the PADEP air toxics website for air samples that were generally collected every six days over a six-year period (2009, 2011-2015). For the Charleroi monitor, the maximum 24-hour VOC measurements and the mean VOC measurements were calculated from the available data. For the Florence monitor, the maximum 24-hour VOC measurements and the mean VOC measurements were extracted from data tabulated by PADEP (2018), except for the acrolein concentrations, which were calculated based on supporting data tables for that report. For all calculations of the mean concentration, non-detect data points were replaced with half of the Method Detection Limit (MDL) prior to calculating the mean, in accordance with standard practices. Notably, neither the Florence nor Charleroi sites measured ethanol or methanol, so these VOCs could not be evaluated using the available data.

3 Results

3.1 Meteorological Conditions

The wind direction measurements from Yonker air monitoring Sites 1 and 2 were evaluated by well pad activity period in two ways: on a daily basis and on an hourly basis (Table A.1). The hourly wind direction analysis showed that winds in this area predominantly blow from the southwesterly and westerly directions, as is also shown in Figure 2.2. The daily average wind direction analysis also showed that the average daily wind direction is typically from the southwesterly, southerly, and westerly directions. Notably, as shown in Figures 2.2 and 2.3, the wind direction measurements at Sites 1 and 2 are not exactly the same, although they generally demonstrate the same predominant wind directions. The differences in measurements between Sites 1 and 2 are likely due to factors such as nearby terrain or buildings, which can cause local variations in wind direction.

Sites 1 and 2 are located northwest of the Yonker well pad in the direction of the Fort Cherry School District campus (Figure 2.1), while Site 3 is located southwest of the well pad; therefore, the predominant winds do not generally blow emissions from the well pad towards the monitoring sites, or towards the Fort Cherry School District campus. However, it is likely that some of the winds blowing from the southerly direction—in addition to the winds blowing from the southeasterly direction—served to transport Yonker well pad air emissions to Sites 1 and 2. The wind direction evaluation shown in Table A.1 demonstrates that there were some days and hours in which this transport pattern occurred, and therefore there are days in which the air monitors at Sites 1 and 2 measured air concentrations reflecting any impacts of Yonker well pad emissions. Likewise, winds from the northeasterly direction would blow the well pad emissions towards Site 3, and winds from this direction occasionally occurred during the different well pad activity periods. Typically, however, winds did not blow from the Yonker well pad towards Site 3, indicating that this site predominantly measures air quality resulting from other sources, which was the intended purpose of this monitoring site. As shown in Figure 1.1, there are many other well pads in the area surrounding the Fort Cherry School District campus, and Site 3 may measure air quality resulting from some of these well pads as well as other regional sources such as transportation emissions. Overall, the wind measurement data provide support for the potential for impacts of Yonker well pad air emissions on the $PM_{2.5}$ and VOC measurements at Sites 1, 2, and 3 on some days and times.

3.2 Air Monitoring Data Summary Statistics and Well Development Phases

3.2.1 Evaluation of $PM_{2.5}$ Measurements

A comparison of the mean and standard deviations of the $PM_{2.5}$ measurements collected at Site 1 (Table 3.1) shows that there are only relatively minor differences in average concentrations between the well pad activity phases, and between the activity and interlude phases. This is supported by the wind direction analysis (Table A.1), which demonstrates that there was little variability in the predominant wind direction during the different activity and non-activity phases. Based on the wind direction analysis, it is likely that the mean $PM_{2.5}$ measurements are associated with regional air quality, rather than the Yonker well pad, because the predominant winds over the monitoring period would have blown any well pad emissions away from the Yonker air quality monitoring sites.

Table 3.1 $PM_{2.5}$ Statistics and HBACVs for Yonker Air Monitoring Site 1

Well Development Period	Mean $PM_{2.5}$ (µg/m^3)	Annual Average $PM_{2.5}$ NAAQS (µg/m^3)[1]	Standard Deviation $PM_{2.5}$ (µg/m^3)	Maximum 24-hour $PM_{2.5}$ (µg/m^3)	24-hour $PM_{2.5}$ NAAQS (µg/m^3)[2]	Total Number of Days in the Period with 24-hour Measurements[3]
Total	7.1	12	4.7	24.6	35	587
Site Setup (Before Jan. 5, 2017)	N/A		N/A	N/A		N/A
Air Drilling (Jan. 5, 2017 – Feb. 18, 2017)	5.4		4.3	7.1		7
Interlude I (Feb. 19, 2017-Mar. 2, 2017)	6.6		4.8	13.6		9
Horizontal Drilling (Mar. 3, 2017- May 7, 2017)	6.8		4.4	14.4		65
Interlude II (May 8, 2017-June 17, 2017)	6.8		4.0	14.2		41
Hydraulic Fracturing (June 18, 2017-Aug. 13, 2017)	7.8		4.3	17.6		54
Interlude III (Aug. 14, 2017-Sept. 7, 2017)	9.5		4.3	13.1		17
Flowback (Sept. 8, 2017-Oct. 23, 2017)	7.0		4.9	14.4		36
Production (After Oct. 23, 2017)	7.1		4.8	24.6		358

Notes:

HBACVs = Health-based Air Comparison Values; NAAQS = National Ambient Air Quality Standards.

(1) The annual average $PM_{2.5}$ NAAQS is appropriate for comparison to the overall mean $PM_{2.5}$ concentration (7.1 µg/m^3) at Yonker Air Monitoring Site 1.

(2) The 24-hour $PM_{2.5}$ NAAQS is appropriate for comparison to the maximum 24-hour $PM_{2.5}$ measurements at Yonker Air Monitoring Site 1.

(3) The maximum 24-hour $PM_{2.5}$ concentration and the number of days in each period with 24-hour measurements were only calculated for days in which there were at least 18 hours of $PM_{2.5}$ data available. The Interlude III maximum 24-hour $PM_{2.5}$ concentration was the only maximum period concentration impacted—*e.g.*, for a day in which only 10 hourly measurements are available, a higher maximum $PM_{2.5}$ concentration of 20.2 µg/m^3 was obtained.

N/A signifies that no data were available for the period.

3.2.2 Evaluation of VOC Measurements

A comparison of summary statistics for 10 VOCs commonly associated with oil and gas activity (Table 3.2) shows that there is some variability between the three air monitoring sites and between the well development phases. At Sites 1 and 2, which are the two sites measuring air quality in the direction of the Fort Cherry School District campus, the maximum concentrations tended to occur during three activity phases: horizontal drilling, production, and flowback. At Site 3, which is the site that less frequently measures air quality resulting from Yonker well pad emissions (see Section 3.1), the maximum concentrations tended to occur during non-activity periods. In addition, higher concentrations of ethanol were measured for a couple of the time periods (*e.g.*, Interlude II, hydraulic fracturing) at Site 3 as compared to Sites 1 and 2.

To further evaluate these maximum concentrations, the wind direction measurements on the days of the maximum measurements at each site were evaluated. At Site 1, the maximum concentrations of ethylbenzene, n-heptane, toluene, xylenes (both o-xylene and m-, p-xylenes), and ethanol were all measured on May 7, 2017, on the last day of the horizontal drilling phase. On this day, 0% of the hourly wind direction measurements at Site 1 were from the S or SE, indicating that the Yonker well pad was not the likely source of the measurements. Rather, the winds were predominantly from the W on May 7, indicating that the emissions source was likely in that direction. At Site 1, the maximum concentrations of benzene, n-hexane, propylene, and methanol occurred on days when 0%, 17%, 4%, and 21% of the hourly wind measurements, respectively, were from the S or SE. This indicates that the Yonker well pad was unlikely to be a source of the maximum benzene detection, and although the Yonker well pad may have contributed to the measured maximum n-hexane, methanol, and propylene concentrations, there likely were other contributing sources. In particular, on the days with the maximum n-hexane, methanol, and propylene measurements, the winds were predominantly from the SW, providing further evidence of an emission source west of the Yonker well pad that contributed to maximum VOC measurements at Site 1.

At Site 2, the maximum ethylbenzene, xylenes (both o-xylene and m-, p-xylenes), toluene, and methanol measurements occurred on May 8, 2018, during the production phase, on a day when 33% of the hourly wind direction measurements were from the S or SE (*i.e.*, from the direction of the Yonker well pad). On this day, 38% of the hourly wind direction measurements were from the SW and W, and 21% were from the NE, indicating that a source in one or both of these directions may have also contributed to the measured maximum VOC concentrations. At Site 2, the maximum n-heptane, n-hexane, and propylene measurements occurred on September 16, 2017, a day when 17% of the hourly wind direction measurements at the site were from the S or SE. On this day, the winds predominantly blew from the NW, N, NE, and E, suggesting a source located to the north or east may have also contributed to the measured concentrations. The maximum measured benzene concentration of 0.369 ppb occurred on a day in 2016 (December 16, 2016) during site preparation before the meteorological equipment was set up. The next highest benzene concentration of 0.331 ppb occurred on February 7, 2018, during the production phase, on a day when both the Site 1 (24 hours of wind data) and Site 2 (only 7 hours of wind data) meteorological data indicated no winds from either the S or SE, indicating that the Yonker well pad was not likely the source of the high benzene concentration. The maximum ethanol concentration occurred on a day when 0% of the hourly wind direction measurements at Site 2 were from the S or SE. On this day (June 9, 2018), the predominant wind directions were winds blowing from the E and SW, and the contractor operating the measurement equipment reported that the data on this day were likely impacted by tractors on nearby hay fields (AECOM, 2018; Cochran, 2019), indicating a source other than the Yonker well pad caused the high ethanol concentration on this day.

There were no wind direction measurements at Site 3, so the meteorological data from Sites 1 and 2 were used to estimate wind conditions at Site 3. At this site, the maximum ethylbenzene, xylenes (both o-xylene and m-, p-xylenes), and methanol measurements occurred on August 29, 2017, a day when the Site 1 station recorded 42% of hourly wind measurements from the NE and when the Site 2 station recorded 0% of hourly wind direction measurements from the NE (and a predominant wind direction from the E). The date was during an interlude period between well pad activities so it is unclear what the source of the VOC emissions could have been if the Yonker well pad contributed to the measured concentrations on this day, as is possible based on the Site 1 wind direction measurements. On this day, the Site 1 and Site 2 stations also recorded 25% and 83% of the hourly wind direction measurements from the E, respectively, suggesting that there was a contributing source in this direction (*i.e.*, a source to the south or southeast of the Yonker well pad). At Site 3, the maximum n-heptane, n-hexane, and propylene concentrations occurred on October 10, 2017, a day when meteorological Sites 1 and 2 measured 21% and 46% of the hourly wind direction measurements from the NE, suggesting the Yonker well pad as a possible contributor to these VOC measurements. On this day, Site 1 also measured 33% of the hourly wind direction measurements from the N, indicating that there could have been a contributing source in this direction (*i.e.*, a source to the west or northwest of the Yonker well pad). As with Site 2, the maximum Site 3 benzene concentration of 0.95 ppb occurred on December 16, 2016, during the site set-up phase before meteorological measurements were available; the next highest benzene concentration of 0.79 ppb was measured on December 3, 2017, during the production phase, when wind data from both the Site 1 and Site 2 monitors indicated an absence of winds from the NE (0% of hourly wind measurements for both monitors). The maximum toluene measurement also occurred on a day during the Interlude II period (May 25, 2017) when 0% of the hourly wind measurements were from the NE, indicating a source other than the well pad. As mentioned above, some higher ethanol concentrations were measured at Site 3 as compared to Sites 1 and 2. The highest ethanol concentrations (*i.e.*, >100 ppb) were measured at Site 3 on two dates during the Interlude II period (May 25 and June 12, 2017), three dates during the hydraulic fracturing phase (June 18, July 30, and August 5, 2017), and one date during production (June 9, 2018). The contractor operating the measurement equipment reported that the June 9, 2018, data were likely impacted by nearby off-road emission sources (AECOM, 2018), so this data point is unlikely to be representative of impacts from the Yonker well pad. On three of these days (May 25, June 12, and August 5, 2017), both meteorological sites recorded no hourly measurements from the NE, and on two of these days (June 18 and July 30, 2017), one of the meteorological stations recorded no hourly measurements from the NE while the other station recorded either 4% or 33% of hourly measurements from the NE. Together, these data suggest that there is a significant source of ethanol impacting Site 3 that is not the Yonker well pad, although the pad may have contributed to some of the higher ethanol measurements.

Table 3.2 VOC Statistics and HBACVs for Yonker Air Monitoring Sites 1, 2, and 3

Compound	**Site 1**				**Site 2**				**Site 3**				**HBACVs**	
	Mean Conc. (ppb)	**Standard Dev. (ppb)**	**Max. Conc. (ppb)**	**Phase in Which Max. Conc. Occurs**	**Mean Conc. (ppb)**	**Standard Dev. (ppb)**	**Max. Conc. (ppb)**	**Phase in Which Max. Conc. Occurs**	**Mean Conc. (ppb)**	**Standard Dev. (ppb)**	**Max. Conc. (ppb)**	**Phase in Which Max. Conc. Occurs**	**Chronic[1]**	**Acute[2]**
Benzene	0.13	0.06	0.29	Production	0.15	0.06	0.37	Site Set-Up	0.17	0.12	0.95	Site Set-Up	4.0	9
Ethylbenzene	0.04	0.10	0.97	Horizontal Drilling	0.04	0.03	0.29	Production	0.04	0.04	0.31	Interlude III	9.2	5,000
n-Heptane	0.11	0.16	1.03	Horizontal Drilling	0.12	0.16	1.32	Flowback	0.14	0.26	2.47	Flowback	97.6	976
n-Hexane	0.23	0.34	2.37	Flowback	0.27	0.48	4.28	Flowback	0.31	0.78	7.57	Flowback	198.6	1,986
Toluene	1.08	7.28	68.70	Horizontal Drilling	0.25	0.45	4.27	Production	0.43	1.21	9.16	Interlude II	1,326.9	2,000
m-,p-Xylenes	0.09	0.27	2.40	Horizontal Drilling	0.08	0.10	0.72	Production	0.08	0.10	0.74	Interlude III	23.0[3]	2,000[3]
o-Xylene	0.05	0.12	1.14	Horizontal Drilling	0.04	0.04	0.33	Production	0.04	0.04	0.32	Interlude III		
Propylene	1.21	2.30	14.30	Interlude II	1.12	2.06	18.00	Flowback	1.33	3.36	32.40	Flowback	1,743	17,431
Ethanol	2.19	1.71	9.86	Horizontal Drilling	16.72	48.09	442.00	Production	73.42	565.02	5900.00	Production	1,000,000	1,000,000
Methanol	8.44	11.01	82.20	Interlude II	11.08	11.20	54.80	Production	13.29	17.52	122.00	Interlude III	15,262	21,367

Notes:

Conc. = Concentration; Dev. = Deviation; HBACVs = Health-based Air Comparison Values; Max. = Maximum; ppb = Parts Per Billion; VOC = Volatile Organic Compound.

(1) The chronic HBACVs are appropriate for comparison to the mean Yonker air monitoring site VOC measurements. The sources of these HBACVs is presented in Table A.3.

(2) The acute HBACVs are appropriate for comparison to the maximum Yonker air monitoring site VOC measurements. The sources of these HBACVs is presented in Table A.2.

(3) Only a single chronic and acute HBACV is shown for m,p-xylenes and o-xylene given that the HBACVs are intended for comparison with total or mixed xylenes concentrations (*i.e.*, summed concentrations for m-,p-, and o-xylenes).

3.3 Public Health Evaluation

3.3.1 Comparison of $PM_{2.5}$ Data with Acute and Chronic HBACVs

The maximum 24-hour $PM_{2.5}$ concentration based on all of the $PM_{2.5}$ data measured at Yonker air monitoring Site 1 is 24.6 $\mu g/m^3$ (Table 3.1). This concentration is well below the acute $PM_{2.5}$ HBACV, which is 35 $\mu g/m^3$. The mean $PM_{2.5}$ concentration based on all of the $PM_{2.5}$ data measured at Site 1 is 7.1 $\mu g/m^3$ (Table 3.1). This concentration is well below the chronic $PM_{2.5}$ HBACV, which is 12 $\mu g/m^3$. Therefore, measured $PM_{2.5}$ concentrations near the Yonker well pad are not expected to be associated with either short-term or chronic health risks.

3.3.2 Comparison of VOC Data with Acute and Chronic HBACVs

The maximum detected 24-hour concentrations at all sites were compared to the acute VOC HBACVs (Table A.2), and the comparisons for a set of key pollutants are shown in Figure 3.1. Acrolein was the only compound with a concentration that exceeded the identified benchmark, and this was for a single measurement at just one of the three monitoring sites. More specifically, an acrolein concentration of 3.5 ppb was reported for the May 31, 2017, sample from Site 1, which is just slightly higher than the acute HBACV of 3 ppb. However, this exceedance was not further evaluated given US EPA's conclusion that acrolein data obtained *via* Method TO-15 are unreliable (see Section 2.1.2).

The mean VOC concentrations at each site were compared to the chronic VOC HBACVs (Table A.3), and the comparisons for a set of key VOCs are shown in Figure 3.2. With the exception of acrolein, all of the Yonker VOC data were lower than the identified chronic HBACVs, and as described in Section 2.1.2, the acrolein measurements are not considered to be accurate.

There are four compounds that were detected at one or more of the Yonker air monitoring sites, but for which no appropriate acute or chronic benchmarks were identified (Hexacloro-1,3-Butadiene; m-Dichlorobenzene; p-Ethyltoluene; and Trichlorofluoromethane). These VOCs are not expected to present either acute or chronic health risks due to the low, sub-ppb detected concentrations, which are generally either less than or of similar magnitude to background concentrations measured at other locations in Washington County, as described in Section 3.3.3.

In summary, the VOC acute and chronic HBACV comparisons demonstrate the absence of measured 24-hour and mean VOC concentrations of public health concern at the three Yonker air monitoring sites.

3.3.3 Comparisons of Yonker Measurements with Washington County Background Concentrations

The 1-hour maximum, 24-hour maximum, and mean $PM_{2.5}$ concentrations at Yonker air monitoring Site 1 were compared to the corresponding statistics from the Florence background site (Table 3.3). For each of these statistics, the Yonker data were within the range of values measured at the Florence background site during 2013-2017. Therefore, the data demonstrate that the $PM_{2.5}$ concentrations near the Yonker well pad are similar to regional background $PM_{2.5}$ concentrations in Washington County. Further, Figure 3.3 shows that the 24-hour average $PM_{2.5}$ measurements at the Yonker and Florence air monitoring sites have similar temporal variations (*i.e.*, day-by-day changes). This figure provides further evidence that the $PM_{2.5}$ concentrations measured at the Site 1 monitor were similar to regional background air concentrations and consistently below the US EPA 24-hour NAAQS of 35 $\mu g/m^3$.

Table 3.3 $PM_{2.5}$ Background Comparisons

Statistic	Yonker Air Monitoring Site[1]	Florence Background Site[2]
1-hr maximum $PM_{2.5}$ concentration ($\mu g/m^3$)	141.0	45.5-156.7
24-hour maximum $PM_{2.5}$ concentration ($\mu g/m^3$)	24.6	19.2-28.5
Mean $PM_{2.5}$ concentration ($\mu g/m^3$)	7.1	7.2-10.6
Standard deviation of $PM_{2.5}$ ($\mu g/m^3$)	4.7	3.2-4.8

Note:

(1) Yonker air monitoring site statistics were calculated using data from Feb. 2017-Oct. 2018.

(2) Florence background site data are the range of values from the 2013-2017 datasets. The mean and standard deviation values are annual means and standard deviations based on 24-hour measurements.

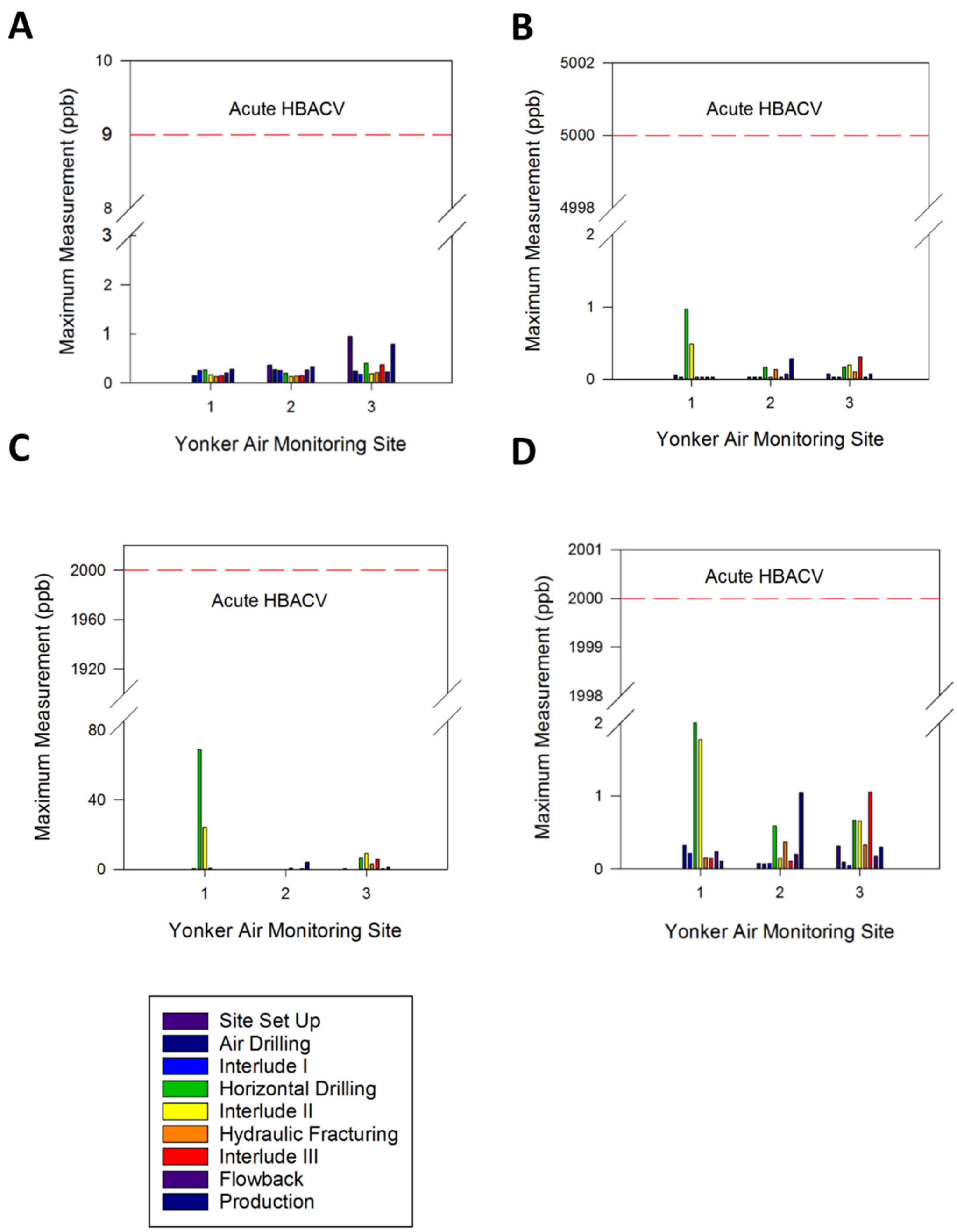

Figure 3.1 Comparison of Maximum Measured 24-hour VOC Concentrations by Monitoring Site and Yonker Well Pad Development Phase with Acute HBACVs: (a) benzene, (b) ethylbenzene, (c) toluene, and (d) xylenes. Table A.2 provides comparisons of maximum measured 24-hour concentrations with acute HBACVs for all measured VOCs. Notably, m,p- and o-xylenes measurements are summed in this figure and Table A.2 because the applicable acute HBACV is for mixed xylenes.

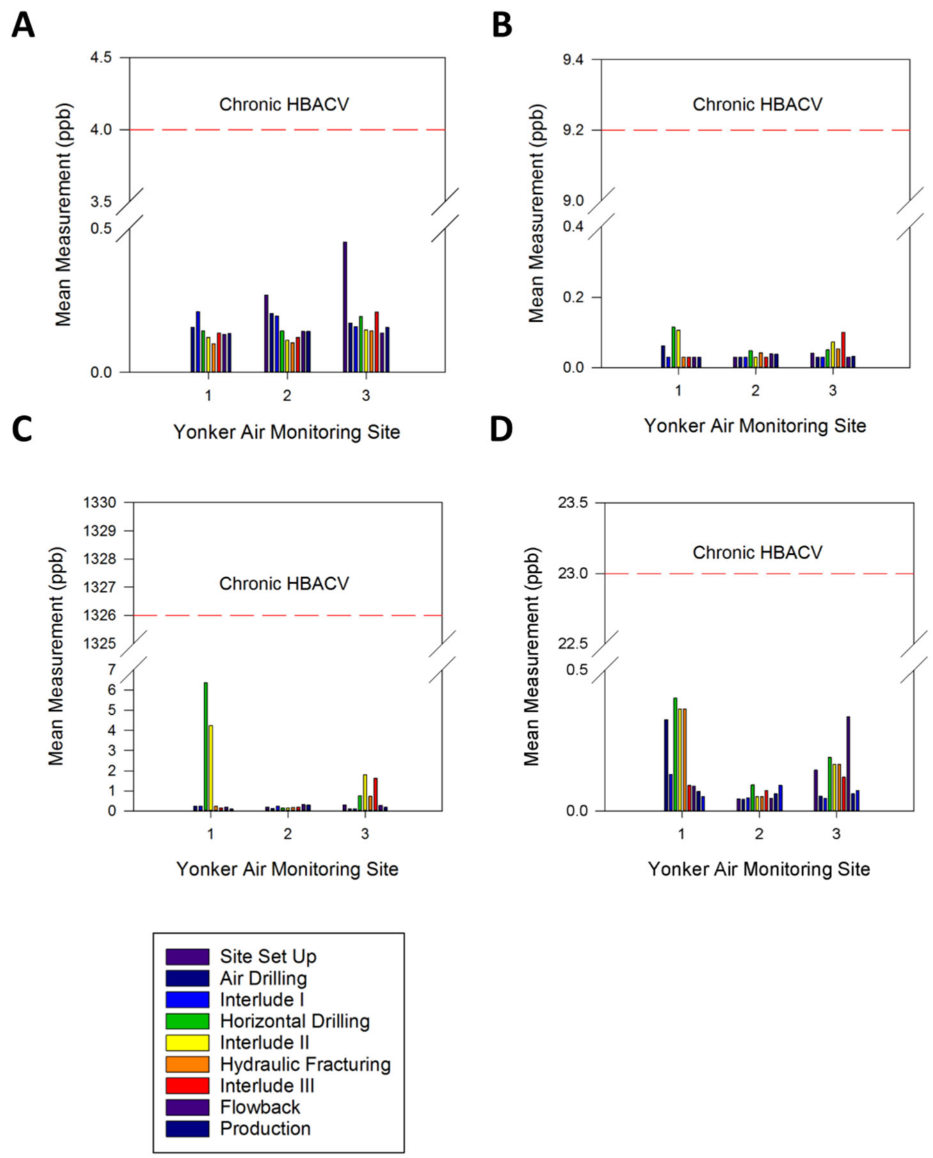

Figure 3.2 Comparison of Mean VOC Concentrations by Monitoring Site and Yonker Well Pad Development Phase with Chronic HBACVs: (a) benzene, (b) ethylbenzene, (c) toluene and (d) xylenes. Table A.3 provides comparisons of mean concentrations with chronic HBACVs for all measured VOCs. Notably, m,p- and o-xylenes measurements are summed in this figure and Table A.3 because the applicable chronic HBACV is for mixed xylenes.

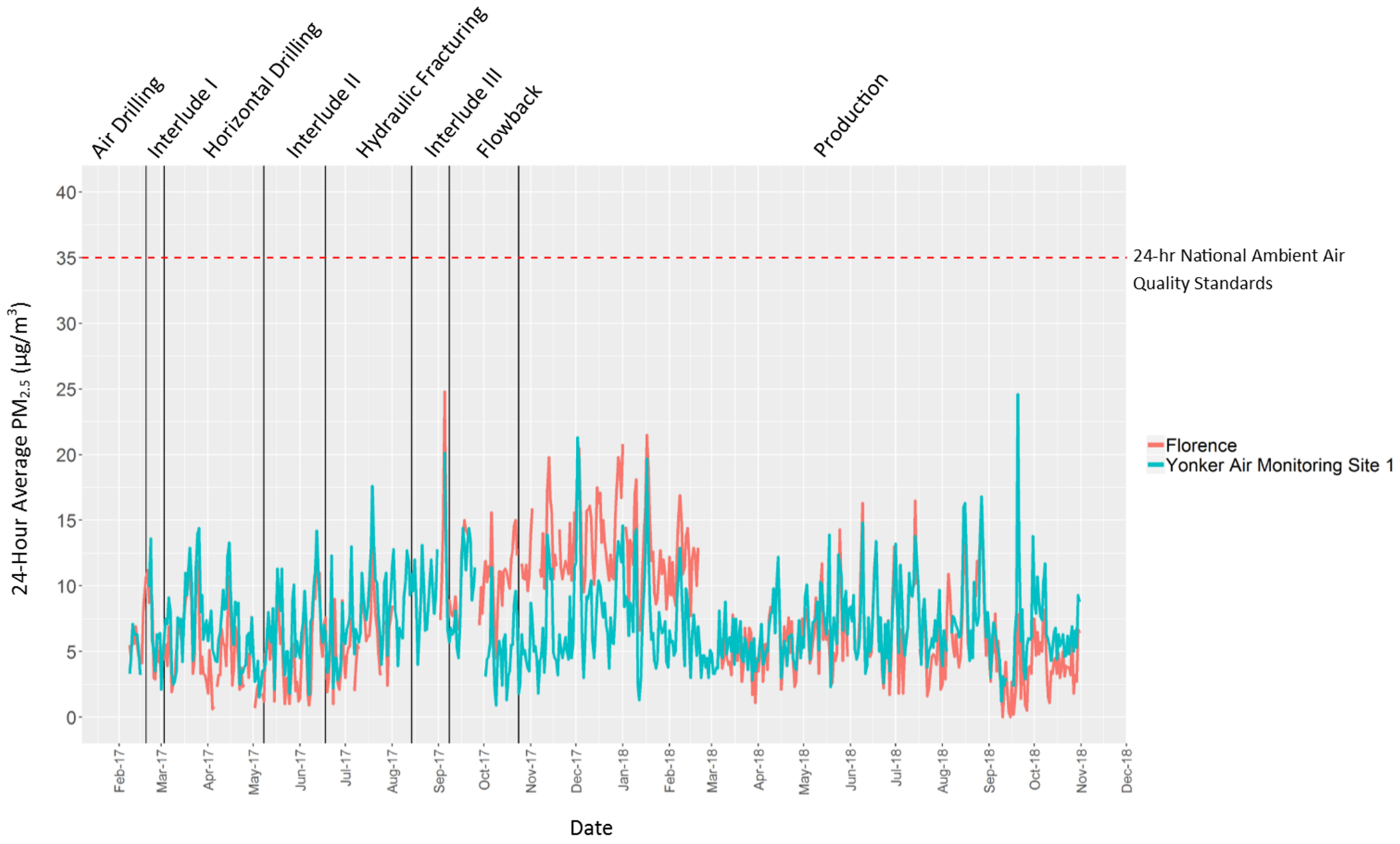

Figure 3.3 Time Series of 24-hour $PM_{2.5}$ Measurements at the Yonker Air Monitoring Site 1 and PADEP Florence Site

The 24-hour maximum and mean VOC measurements at the three Yonker air monitoring sites were compared to the corresponding statistics for the PADEP Florence and Charleroi sites (Tables A.4 and A.5). The majority of the mean VOC concentrations for the Yonker air monitoring sites were below or similar to the values measured at the background sites, indicating that Yonker well pad emissions were not contributing to elevated concentrations of most VOC species at the three air monitoring sites.

The 24-hour maximum VOC measurements at one or more of the Yonker air monitoring sites were substantially higher than the maximum measured background concentrations for some of the VOC analytes (*e.g.*, for acetone, methylene chloride, n-hexane, propylene, and toluene). These peak measurements were further explored using the wind direction data. For acetone, all measurements at Site 2 were within the range of the background sites (*i.e.*, within the range of 12.31-29.00 ppb). Site 1 had one acetone measurement (212 ppb) that was significantly higher than background measurements, but all other measurements were within the range of background. The maximum acetone measurement at this site occurred on May 31, 2017, during the Interlude II period (*i.e.*, a period between well pad activities), when 21% of the hourly wind measurements at Site 1 were from the S or SE (*i.e.*, from the direction of the Yonker well pad). The predominant wind direction on this day was from the SW, with 63% of hourly wind measurements from that direction. This suggests that the Yonker well pad could have contributed to this anomalously high acetone concentration, but it is likely that some other source to the SW of the meteorological site also contributed to the high acetone measurement. The maximum measured acetone concentration at Site 3 was 43.5 ppb. This measurement occurred on August 29, 2017, during the Interlude III period, and the next highest acetone concentrations (29.3-36.4 ppb) were measured at Site 3 on May 25, June 12, and June 18, 2017, either during the Interlude II period or at the beginning of the hydraulic fracturing phase. On two of these days (May 25 and June 12, 2017), both meteorological sites (Sites 1 and 2) recorded no hourly measurements from the NE (*i.e.*, from the direction of the Yonker well pad), and on two of these days (June 18 and August 29, 2017), one of the meteorological stations recorded no hourly measurements from the NE but the other station recorded 4% or 42% of hourly measurements from the NE. Together, these data suggest the well pad as a possible contributing source to some of the maximum measured acetone measurements, but also suggest the presence of other acetone sources not related to the Yonker well pad.

The highest methylene chloride measurements all occurred during the flowback and production phases at Sites 1 and 2, including on September 22 and September 28, 2017 (30.3 and 27.4 ppb, respectively) for Site 1 and on September 28, 2017; May 20, 2018; and July 1, 2018 (27.4, 9.34, and 11.0 ppb, respectively) for Site 2. Wind direction data on September 22, 2017, showed that 29% of the hourly measurements at Site 1 originated from the S or SE, and wind direction data at Sites 1 and 2 on September 28, 2017, showed that 0% of the hourly measurements originated from the S or SE. Wind direction data at Site 2 showed that 0% and 79% of the hourly wind direction measurements were from the S and SE on May 20, 2018, and July 1, 2018. Based on these wind direction measurements, it is likely that other sources in addition to the Yonker well pad contributed to the maximum measured methylene chloride measurements at Sites 1 and 2. For Site 3, the highest methylene chloride concentrations ranging from 5.91 to 19.7 ppb occurred during the Interlude II period (May 25 and June 12, 2017), hydraulic fracturing phase (June 18, July 30, and August 5, 2017), and production phase (September 29 and October 5, 2018). On most of these days, both meteorological sites recorded few hourly wind direction measurements originating from the NE, although on one of the days (July 30, 2017), Site 2 recorded 33% of wind direction measurements from the NE. These data suggest that sources other than the Yonker well pad may have been more important contributors to the highest methylene chloride concentrations measured at Site 3.

Sites 1 and 2 had n-hexane concentration in excess of the Charleroi and Florence background measurements on a few days (*i.e.*, in excess of 1.5 ppb). At Site 1, there were three days with measurements >1.5 ppb (May 7, September 16, and October 4, 2017), although all measurements were ≤2.37 ppb. On one of these days, 0% of the hourly wind direction measurements were from the S or SE, and on the remaining two days, 17-42% of the hourly measurements were from these directions, indicating that the Yonker well pad was a possible contributor to the measured n-hexane concentrations. At Site 2, there were three days with measurements >1.5 ppb (4.28 ppb on September 16; 1.69 ppb on October 4, 2017; and 1.97 on May 8, 2018). The hourly wind direction measurements at Site 2 indicated that 8-33% of the measurements were from the S or SE on these three days, suggesting that the Yonker well pad was a possible source of the measured concentrations. At Site 3, there were three days with measurements >1.5 ppb (3.14 ppb on December 16, 2016; 1.71 ppb on September 22, 2017; and 7.57 ppb on October 10, 2017). The 2016 measurement occurred before meteorological equipment was installed at Sites 1 and 2. The wind direction measurements at the two sites indicate that 21-54% of the hourly wind direction measurements were from the NE on the two 2017 dates, indicating that the Yonker well pad may have contributed to the measured concentrations.

All three sites had propylene concentrations in excess of the Charleroi and Florence measurements (*i.e.*, in excess of 8.0 ppb), albeit for just a few samples. Site 1 had propylene concentrations ranging from 8.3-14.3 ppb on May 25, May 31, September 16, and October 4, 2017, and on these days 4-42% of the hourly wind direction measurements at the site were from the S and SE. Site 2 had propylene concentrations ranging from 8.37-18.0 ppb on June 6, September 16, and October 4, 2017, and on these days, 0-17% of the hourly wind direction measurements at the site were from the S and SE. For Site 3, the maximum measured propylene concentration of 32.4 ppb occurred on October 10, 2017, while there were propylene measurements of 10.9 and 10.6 ppb on December 16, 2016, and September 22, 2017, respectively. The 2016 measurement was collected before meteorological measurements were available from Sites 1 and 2, and the meteorological data for the 2017 dates show that 21-54% of the hourly wind direction measurements were from the NE. Overall, the data indicate that the higher propylene concentrations at the three sites may have been influenced by Yonker well pad emissions.

All three sites had one or more toluene measurement above the range of background concentrations (*i.e.*, above 2.76 ppb). At Site 1, all toluene measurements were within range of the background measurements except for measurements of 68.7 ppb on May 7, 2017, and 24.2 ppb on May 25, 2017. Wind direction measurements at Site 1 on May 7 indicate that 0% of the hourly measurements originated from the S and SE, while only 4% of hourly measurements originated from the S and SE on May 25; predominant winds for these days were either from the W or SW. Therefore, it is likely that these toluene measurements are influenced by a source located to the west or southwest of the monitoring site, rather than the Yonker well pad. At Site 2, there was one toluene measurement of 4.27 ppb on May 8, 2018, a day in which 33% of the winds originated from the S and SE, suggesting that the Yonker well pad may have contributed to this measurement. At Site 3, there were measurements of toluene ranging from 3.03-9.16 ppb on April 19, May 25, July 12, and August 29, 2017. On two of these days, both meteorological sites recorded 0% of the hourly wind direction measurements from the NE, and on the other two days, one of the meteorological sites recorded 0% of measurements from the NE, but the other site recorded 4% or 42% of hourly wind direction measurements from the NE. Therefore, it is possible that the Yonker well pad contributed to some of the higher toluene measurements, but there were likely other contributing sources.

4 Conclusions

Our air quality and public health evaluation of December 2016 to October 2018 ambient air quality data collected at three sites in proximity to the Yonker well pad in Mount Pleasant Township showed that measured $PM_{2.5}$ and VOC concentrations were consistently below health-based air comparison values and thus are not expected to pose acute or chronic health concerns. Importantly, the monitoring data for Sites 1 and 2, which are located between the Yonker well pad and the Fort Cherry School District campus, indicate an absence of air quality impacts of potential health concern at the Fort Cherry School District campus associated with Yonker well pad air emissions. This conclusion is based on a large dataset with air monitoring results for each phase of development at the Yonker well pad, including a year of data collected during the production phase. In addition, our wind direction evaluation demonstrated that the predominant winds are from the south and southwest and therefore do not transport emissions from the Yonker well pad towards the school campus.

For $PM_{2.5}$, we observed relatively minor differences in average concentrations between the different well activity phases and between the activity phases and the interlude periods of lesser activity that occurred between the specific activity phases. Based on findings from the wind direction analysis that the predominant winds over the monitoring period would have generally blown any well pad air emissions away from the Yonker air monitoring sites, and the similarity of the Yonker $PM_{2.5}$ data with $PM_{2.5}$ data from the PADEP Florence background site in Washington County, it is likely that the mean $PM_{2.5}$ measurements are associated with regional air quality rather than the Yonker well pad. Potential sources of regional $PM_{2.5}$ air quality include not only other natural gas development sites, but also motor vehicles, power plants and other fossil fuel combustion (*e.g.*, residential wood burning), industrial processes, and transport from outside the area. For VOCs, there was no consistent pattern of elevated VOC concentrations at any of the sites or for any of the well pad activity phases, which is consistent with our wind direction analysis that showed predominant winds from the southwesterly and westerly directions- *i.e.*, not for directions that would have blown air emissions from the Yonker well pad towards any of the air monitoring sites. Yonker well pad emissions may have contributed to some of the higher measured 24-hour VOC concentrations, although our wind direction analysis demonstrated that a number of the higher measured concentrations occurred on days with few if any winds from the direction of the Yonker well pad.

While winds in the direction of the monitoring sites from the Yonker well pad were relatively infrequent, there is extensive local Marcellus Shale development in the area, meaning that the monitoring data also provide insights on the potential for air quality impacts from other unconventional natural gas development sites near the Fort Cherry School District campus (see Figure 1.1). However, the $PM_{2.5}$ and VOC data do not provide evidence of elevated long-term average concentrations relative to other parts of Washington County that are more distant from local natural gas development, including in particular the PADEP Florence monitoring site that is considered by PADEP to be a background site primarily impacted by regional air pollutant transport (PADEP, 2018).

Our findings of a general absence of $PM_{2.5}$ and VOC concentrations of either acute or chronic health concern are consistent with air monitoring data collected by PADEP in other southwestern PA locations nearby to unconventional natural gas development activities, including in particular data recently reported for the PADEP "Long-term Ambient Air Monitoring Project: Marcellus Shale Gas Facilities" (PADEP, 2018). For this study, $PM_{2.5}$, VOCs, and other air pollutants (*e.g.*, nitrogen dioxide [NO_2], aldehydes, hydrogen sulfide [H_2S]) were monitored at four sites in Washington County between July 2012 and December 2013. These air monitoring sites are surrounded by producing well pads and are also in close proximity (as close as <0.5

miles) to other major unconventional natural gas development facilities, including a large natural gas processing facility and compressor stations. For measured criteria air pollutants including $PM_{2.5}$, PADEP (2018) reported an absence of any exceedances of the NAAQS and concluded that "the pattern of recorded pollutant concentration measurements did not indicate a localized source impact which would cause an exceedance of any of the NAAQS evaluated." For measured VOCs, PADEP (2018) estimated chronic cancer risks and non-cancer hazards, concluding that they were comparable to those for a historical PA background ambient monitoring site.

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Appendix A

Supporting Data Tables

Table A.1 Wind Speed and Direction Evaluation at Yonker Air Monitoring Sites 1 and 2

Met Site 1																	
Activity Period	Average Wind Speed (mph)	Percent of days with average wind direction in category (%)								Percent of hours with wind direction in category (%)							
		N	NE	E	SE	S	SW	W	NW	N	NE	E	SE	S	SW	W	NW
Total	4	0	5	10	10	24	38	12	1	9	9	10	7	8	36	14	6
Site Setup (Before Jan 5, 2017)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Air Drilling (Jan 5, 2017-Feb 18, 2017)	6	0	9	0	0	9	55	27	0	5	2	2	6	5	41	31	8
Interlude I (Feb 19, 2017-Mar 2, 2017)	9	0	0	0	0	33	42	25	0	1	1	7	3	7	53	26	1
Horizontal Drilling (Mar 3, 2017- May 7, 2017)	5	0	2	18	8	20	30	23	0	10	6	18	6	4	29	18	9
Interlude II (May 8, 2017-Jun 17, 2017)	3	0	2	15	5	22	54	0	2	6	10	12	5	9	38	14	7
Hydraulic Fracturing (Jun 18, 2017-Aug 13, 2017)	3	0	4	7	9	25	47	9	0	10	7	4	8	11	46	11	5
Interlude III (Aug 14, 2017-Sept 7, 2017)	2	0	8	16	8	20	44	4	0	8	14	10	9	13	31	11	4
Flowback (Sept 8, 2017-Oct 23, 2017)	2	0	7	11	24	37	20	2	0	10	11	18	13	13	27	5	3
Production (After Oct 23, 2017)	4	0	6	9	10	24	38	12	1	10	9	9	7	8	36	14	6

Met Site 2																	
Activity Period	Average Wind Speed (mph)	Percent of days with average wind direction in category (%)								Percent of hours with wind direction in category (%)							
		N	NE	E	SE	S	SW	W	NW	N	NE	E	SE	S	SW	W	NW
Total	5	0	3	14	12	21	31	17	2	6	8	13	5	9	20	22	7
Site Setup (Before Jan 5, 2017)	9	0	0	6	6	25	31	31	0	1	2	11	13	8	21	40	4
Air Drilling (Jan 5, 2017-Feb 18, 2017)	8	0	0	6	0	35	12	47	0	4	5	6	7	8	19	39	12
Interlude I (Feb 19, 2017-Mar 2, 2017)	9	0	0	0	0	42	25	33	0	0	0	3	9	14	32	38	4
Horizontal Drilling (Mar 3, 2017- May 7, 2017)	8	0	5	17	8	17	31	20	3	8	8	18	6	8	15	24	12
Interlude II (May 8, 2017-Jun 17, 2017)	5	0	2	12	7	22	44	10	2	4	9	15	4	7	27	27	7
Hydraulic Fracturing (Jun 18, 2017-Aug 13, 2017)	6	0	2	7	7	12	44	28	0	6	9	5	3	5	32	33	7
Interlude III (Aug 14, 2017-Sept 7, 2017)	5	0	4	20	16	12	32	16	0	5	11	22	5	5	19	27	6
Flowback (Sept 8, 2017-Oct 23, 2017)	4	0	2	13	30	30	17	7	0	8	12	26	7	9	18	14	7
Production (After Oct 23, 2017)	4	0	3	16	13	22	30	13	3	7	8	13	5	11	20	19	7

Notes:

E = East; mph = Miles Per Hour; N = North; NE = Northeast; NW = Northwest; S = South; SE = Southeast; SW = Southwest; W = West.

The yellow columns signify the wind direction most likely to influence air monitoring Site 3, and the blue columns signify the wind directions most likely to influence air monitoring Sites 1 and 2.

N/A signifies that no data were available for the period.

Table A.2 Maximum 24-hour VOC Data Comparisons to Acute Benchmarks

Compound	Acute Health-based Benchmark (ppb)	Benchmark Source	Maximum Measurement (ppb)		
			Site 1	Site 2	Site 3
1,1,1-Trichloroethane	2,000	ATSDR acute inhalation MRL	ND	ND	ND
1,1,2,2-Tetrachloroethane	N/A	N/A	ND	ND	ND
1,1,2-Trichloroethane	0.4	Chronic US EPA RfC multiplied by 10	0.0686	ND	0.123
1,1-Dichloroethane	N/A	N/A	ND	ND	ND
1,1-Dichloroethylene	504.8	Chronic US EPA RfC multiplied by 10	ND	ND	ND
1,2,4-Trichlorobenzene	2.7	Chronic US EPA RfC multiplied by 10	0.147	0.101	0.123
1,2,4-Trimethylbenzene	122.1	Chronic US EPA RfC multiplied by 10	2.71	0.403	0.457
1,2-Dibromoethane	11.7	Chronic US EPA RfC multiplied by 10	ND	ND	ND
1,2-Dichloroethane	17.3	Chronic US EPA RfC multiplied by 10	0.122	0.165	0.566
1,2-Dichloropropane	50	ATSDR acute inhalation MRL	ND	ND	0.115
1,3,5-Trimethylbenzene	122	Chronic US EPA RfC multiplied by 10	0.786	0.137	0.243
1,3-Butadiene	298.3	ORNL RAIS acute inhalation RfC	0.0584	0.122	0.264
1-Bromopropane	1,000	ATSDR acute inhalation MRL	0.249	0.0654	ND
2-Butanone	16,955.60	Chronic US EPA RfC multiplied by 10	1.93	2.08	5.77
2-Hexanone	73.2	Chronic US EPA RfC multiplied by 10	0.14	0.269	1.27
Acetone	26,000	ATSDR acute inhalation MRL	212	27.7	43.5
Acrolein	3	ATSDR acute inhalation MRL	3.5	1.84	2.05
Benzene	9	ATSDR acute inhalation MRL	0.288	0.369	0.947
Bromodichloromethane	N/A	N/A	ND	ND	ND
Bromoform	N/A	N/A	ND	ND	ND
Bromomethane	50	ATSDR acute inhalation MRL	ND	0.0677	0.0697
c-1,2-Dichloroethylene	N/A	N/A	ND	ND	ND
c-1,3-Dichloropropene	44.1	Chronic US EPA RfC multiplied by 10	ND	ND	ND
Carbon Tetrachloride	302.0	ORNL RAIS acute inhalation RfC	0.112	0.206	0.127
Chlorobenzene	108.6	Chronic US EPA RfC multiplied by 10	ND	0.0637	0.0728
Chloroethane	15,000	ATSDR acute inhalation MRL	0.21	0.545	1.37
Chloroform	100	ATSDR acute inhalation MRL	0.25	3.21	0.574
Chloromethane	500	ATSDR acute inhalation MRL	1.62	2.21	1.66
Cyclohexane	17,431.10	Chronic US EPA RfC multiplied by 10	1.1	2.49	0.885
Dibromochloromethane	N/A	N/A	ND	ND	ND
Dichlorodifluoromethane	202.2	Chronic US EPA RfC multiplied by 10	0.629	0.932	0.679
Ethanol[1]	1,000,000	NIOSH REL	9.86	442	5900.00
Ethylbenzene	5000	ATSDR acute inhalation MRL	0.965	0.288	0.311
Freon 113	6,523.80	RfC	0.0886	0.136	0.0961
Freon 114	N/A	N/A	ND	ND	ND
Hexachloro-1,3-Butadiene	N/A	N/A	0.0592	ND	0.0787
m-Dichlorobenzene	N/A	N/A	0.0929	0.152	0.165
Methanol	21367.0	ORNL RAIS acute inhalation RfC	82.2	54.8	122
Methyl t-Butylether	2,000	ATSDR acute inhalation MRL	ND	ND	0.13
Methylene Chloride	600	ATSDR acute inhalation MRL	30.3	27.4	19.7
Methylisobutylketone	7,323.30	Chronic US EPA RfC multiplied by 10	0.183	0.121	0.311
n-Heptane	976	Chronic US EPA RfC multiplied by 10	1.03	1.32	2.47
n-Hexane	1,986	Chronic US EPA RfC multiplied by 10	2.37	4.28	7.57
o-Dichlorobenzene	332.6	Chronic US EPA RfC multiplied by 10	0.069	0.0918	0.157
p-Dichlorobenzene	2,000	ATSDR acute inhalation MRL	0.125	0.146	0.159
p-Ethyltoluene	N/A	N/A	0.545	0.263	0.29
Propylene	17,431.10	Chronic US EPA RfC multiplied by 10	14.3	18	32.4
Styrene	5,000	ATSDR acute inhalation MRL	0.477	0.726	0.647
t-1,2-Dichloroethylene	200	ATSDR acute inhalation MRL	ND	ND	ND
t-1,3-Dichloropropene	44.1	Chronic US EPA RfC multiplied by 10	ND	ND	ND
Tetrachloroethylene	6	ATSDR acute inhalation MRL	0.128	0.206	0.0736
Tetrahydrofuran	6,782.20	Chronic US EPA RfC multiplied by 10	0.295	0.501	0.402
Toluene	2,000	ATSDR acute inhalation MRL	68.7	4.27	9.16
Trichloroethylene	3.7	Chronic US EPA RfC multiplied by 10	0.0698	0.105	ND
Trichlorofluoromethane	N/A	N/A	0.333	0.581	0.38
Vinyl Chloride	500	ATSDR acute inhalation MRL	ND	0.0654	ND
Xylenes[2]	2,000	ATSDR acute inhalation MRL	1.772	1.05	1.057

Notes:

ATSDR = Agency for Toxic Substances and Disease Registry; MRL = Minimal Risk Level; NIOSH = US National Institute for Occupational Safety and Health; ORNL = Oak Ridge National Laboratory; ppb = Parts Per Billion; RAIS = Risk Assessment Information System; REL = Recommended Exposure Limit; RfC = Reference Concentration; US EPA = United States Environmental Protection Agency.

N/A indicates that there is not an ATSDR acute inhalation MRL, chronic US EPA RfC, or ORNL RAIS acute inhalation RfC for the compound. ND indicates that the compound was not detected at a concentration above the measurement detection limit.

Acute benchmarks were selected using the following order of preference: 1) ATSDR acute inhalation MRL, 2) ORNL RAIS acute inhalation RfC, 3) chronic US EPA RfC multiplied by 10. If the benchmarks were available in units of mass per cubic meter, they were converted to ppb assuming sea level pressure (101325 Pa) and a temperature of 25° C.

(1) No ATSDR acute inhalation MRL or ORNL RAIS acute inhalation RfC is currently available for ethanol. The value shown is the NIOSH time-weighted average REL for ethanol that is intended to be protective of worker health for up to a 10-hour workday during a 40-hour workweek over a working lifetime (note that the NIOSH REL for ethanol is equivalent to the U.S. Occupational Safety and Health Administration [OSHA] permissible exposure limit [PEL] for ethanol, as well as the American Conference of Governmental Industrial Hygienists [ACGIH] 15-minute Threshold Limit Value–Short-term Exposure Limit [TLV-TWA] for ethanol). While this is an occupational exposure value (*i.e.* , not residential), it is a reasonable value to use for this evaluation, given the low toxicity of ethanol. Notably, the maximum ethanol measurements at Site 2 (442 ppb) and Site 3 (5,900 ppb) were recorded on Jun. 9, 2018; the contractor collecting the measurements indicated that on this day, there was potential contamination or impact from nearby mobile off-road emissions sources.

(2) The xylenes measurements at the three Yonker sites represent the sum of m-,p- xylenes and o-xylene measurements.

Table A.3 Mean VOC Data Comparisons to Chronic Benchmarks

Compound	Chronic Health-based Benchmark (ppb)	Benchmark Source	Mean Measurement (ppb)[1]					
			Total			Production Phase Only		
			Site 1	Site 2	Site 3	Site 1	Site 2	Site 3
1,1,1-Trichloroethane	916.3	US EPA RfC	ND	ND	ND	ND	ND	ND
1,1,2,2-Tetrachloroethane	0.3	US EPA IUR	ND	ND	ND	ND	ND	ND
1,1,2-Trichloroethane	0.04	US EPA RfC	0.03	ND	0.03	0.03	ND	0.03
1,1-Dichloroethane	15.4	US EPA IUR	ND	ND	ND	ND	ND	ND
1,1-Dichloroethylene	50.5	US EPA RfC	ND	ND	ND	ND	ND	ND
1,2,4-Trichlorobenzene	0.3	US EPA RfC	0.03	0.03	0.03	0.03	0.03	0.03
1,2,4-Trimethylbenzene	12.2	US EPA RfC	0.08	0.04	0.04	0.03	0.03	0.03
1,2-Dibromoethane	0.02	US EPA IUR	ND	ND	ND	ND	ND	ND
1,2-Dichloroethane	1.0	US EPA IUR	0.03	0.03	0.04	0.03	0.03	0.03
1,2-Dichloropropane	0.9	US EPA RfC	ND	ND	0.03	ND	ND	0.03
1,3,5-Trimethylbenzene	12.2	US EPA RfC	0.04	0.03	0.03	0.03	0.03	0.03
1,3-Butadiene	0.9	US EPA RfC	0.03	0.03	0.04	0.03	0.03	0.03
1-Bromopropane	19.9	US EPA RfC	0.03	0.03	ND	0.03	0.03	ND
2-Butanone	1695.6	US EPA RfC	0.45	0.54	0.61	0.37	0.46	0.45
2-Hexanone	7.3	US EPA RfC	0.04	0.05	0.06	0.04	0.04	0.04
Acetone	13050.1	US EPA RfC	6.01	5.40	5.86	2.78	5.41	4.11
Acrolein	0.009	US EPA RfC	0.32	0.40	0.36	0.24	0.40	0.29
Benzene	4.0	US EPA IUR	0.13	0.15	0.17	0.14	0.14	0.16
Bromodichloromethane	0.4	US EPA IUR	ND	ND	ND	ND	ND	ND
Bromoform	8.8	US EPA IUR	ND	ND	ND	ND	ND	ND
Bromomethane	1.3	US EPA RfC	ND	0.03	0.03	ND	0.03	0.03
c-1,2-Dichloroethylene	N/A	N/A	ND	ND	ND	ND	ND	ND
c-1,3-Dichloropropene	4.4	US EPA RfC	ND	ND	ND	ND	ND	ND
Carbon Tetrachloride	2.7	US EPA IUR	0.08	0.09	0.08	0.09	0.09	0.09
Chlorobenzene	10.9	US EPA RfC	ND	0.03	0.03	ND	0.03	0.03
Chloroethane	3789.5	US EPA RfC	0.04	0.04	0.06	0.03	0.03	0.03
Chloroform	0.9	US EPA IUR	0.03	0.07	0.04	0.03	0.03	0.03
Chloromethane	43.6	US EPA RfC	0.56	0.57	0.56	0.49	0.51	0.49
Cyclohexane	1743.1	US EPA RfC	0.06	0.08	0.08	0.04	0.10	0.07
Dibromochloromethane	N/A	N/A	ND	ND	ND	ND	ND	ND
Dichlorodifluoromethane	23.8	US EPA RfC	0.41	0.43	0.42	0.37	0.38	0.37
Ethanol[2]	1000000	NIOSH REL	2.19	16.27	73.42	1.82	23.67	101.77
Ethylbenzene	9.2	US EPA IUR	0.04	0.04	0.04	0.03	0.04	0.03
Freon 113	652.4	US EPA RfC	0.07	0.07	0.07	0.07	0.07	0.07
Freon 114	N/A	N/A	ND	ND	ND	ND	ND	ND
Hexachloro-1,3-Butadiene	0.4	US EPA IUR	0.03	ND	0.03	0.03	ND	0.03
m-Dichlorobenzene	N/A	N/A	0.03	0.03	0.03	0.03	0.03	0.03

Compound	Chronic Health-based Benchmark (ppb)	Benchmark Source	Mean Measurement (ppb)[1]					
			Total			Production Phase Only		
			Site 1	Site 2	Site 3	Site 1	Site 2	Site 3
Methanol	15262.2	US EPA RfC	8.44	11.08	13.29	4.83	9.55	9.46
Methyl t-Butylether	106.7	US EPA IUR	ND	ND	0.03	ND	ND	0.03
Methylene Chloride	172.7	US EPA RfC	0.72	1.15	1.00	0.11	1.17	0.69
Methylisobutylketone	732.3	US EPA RfC	0.03	0.04	0.04	0.03	0.05	0.03
n-Heptane	97.6	US EPA RfC	0.11	0.12	0.14	0.07	0.10	0.09
n-Hexane	198.6	US EPA RfC	0.23	0.27	0.31	0.16	0.24	0.21
o-Dichlorobenzene	33.3	US EPA RfC	0.03	0.03	0.03	0.03	0.03	0.03
p-Dichlorobenzene	1.5	US EPA IUR	0.03	0.03	0.03	0.03	0.03	0.03
p-Ethyltoluene	N/A	N/A	0.04	0.04	0.03	0.03	0.03	0.03
Propylene	1743.1	US EPA RfC	1.21	1.12	1.33	0.62	0.66	0.69
Styrene	234.8	US EPA RfC	0.04	0.07	0.06	0.03	0.09	0.05
t-1,2-Dichloroethylene	N/A	N/A	ND	ND	ND	ND	ND	ND
t-1,3-Dichloropropene	4.4	US EPA RfC	ND	ND	ND	ND	ND	ND
Tetrachloroethylene	5.9	US EPA RfC	0.03	0.03	0.03	0.03	0.03	0.03
Tetrahydrofuran	678.2	US EPA RfC	0.04	0.04	0.04	0.03	0.04	0.03
Toluene	1326.9	US EPA RfC	1.08	0.25	0.43	0.11	0.30	0.19
Trichloroethylene	0.4	US EPA RfC	0.03	0.03	ND	0.03	0.03	ND
Trichlorofluoromethane	N/A	N/A	0.24	0.26	0.25	0.23	0.26	0.24
Vinyl Chloride	8.9	US EPA IUR	ND	0.03	ND	ND	0.03	ND
Xylenes[3]	23.0	US EPA RfC	0.12	0.10	0.10	0.05	0.09	0.07

Notes:

IUR = Inhalation Unit Risk; NIOSH = US National Institute for Occupational Safety and Health; ppb = Parts Per Billion; REL = Recommended Exposure Limit; RfC = Reference Concentration; US EPA = United States Environmental Protection Agency.

N/A indicates that there is not an US EPA RfC or IUR for the compound. ND indicates that the compound was not detected at concentration above the measurement detection limit.

The IURs were converted to units of µg/m3 assuming 1 in 10,000 risk. The IURs and RfCs were converted from units of mass per cubic meter to ppb assuming sea level pressure (101325 Pa) and a temperature of 25° C.

(1) If at least one measurement at a given site was above detection limit, half of the detection limit was substituted for any measurements below detection limit before calculating the mean.

(2) No US EPA RfC is currently available for ethanol. The value shown is the NIOSH time-weighted average REL for ethanol that is intended to be protective of worker health for up to a 10-hour workday during a 40-hour workweek over a working lifetime (note that the NIOSH REL for ethanol is equivalent to the U.S. Occupational Safety and Health Administration (OSHA) permissible exposure limit [PEL] for ethanol, as well as the American Conference of Governmental Industrial Hygienists (ACGIH) 15-minute Threshold Limit Value–Short-term Exposure Limit (TLV-TWA) for ethanol). While this is an occupational exposure value (*i.e.* , not residential), it is a reasonable value to use for this evaluation, given the low toxicity of ethanol.

(3) The xylenes measurements at the three Yonker sites represent the sum of m-,p- xylenes and o-xylene measurements.

Table A.4 Maximum 24-hour VOC Background Comparisons

Compound	Maximum Measurement (ppb)				
	Charleroi	Florence	Yonker Site 1	Yonker Site 2	Yonker Site 3
1,1,1-Trichloroethane	1.63	ND	ND	ND	ND
1,1,2,2-Tetrachloroethane	ND	ND	ND	ND	ND
1,1,2-Trichloroethane	ND	ND	0.07	ND	0.12
1,1-Dichloroethane	ND	ND	ND	ND	ND
1,1-Dichloroethylene	ND	ND	ND	ND	ND
1,2,4-Trichlorobenzene	0.16	ND	0.15	0.10	0.12
1,2,4-Trimethylbenzene	0.29	ND	2.71	0.40	0.46
1,2-Dibromoethane	ND	ND	ND	ND	ND
1,2-Dichloroethane	0.04	0.03	0.12	0.17	0.57
1,2-Dichloropropane	0.06	ND	ND	ND	0.12
1,3,5-Trimethylbenzene	0.14	ND	0.79	0.14	0.24
1,3-Butadiene	ND	ND	0.06	0.12	0.26
1-Bromopropane	0.34	ND	0.25	0.07	ND
2-Butanone	3.87	1.07	1.93	2.08	5.77
2-Hexanone	0.73	ND	0.14	0.27	1.27
Acetone	29.00	12.31	212.00	27.70	43.50
Acrolein	1.80	0.86	3.50	1.84	2.05
Benzene	3.12	0.59	0.29	0.37	0.95
Bromodichloromethane	0.06	ND	ND	ND	ND
Bromoform	ND	ND	ND	ND	ND
Bromomethane	0.22	ND	ND	0.07	0.07
c-1,2-Dichloroethylene	ND	ND	ND	ND	ND
c-1,3-Dichloropropene	ND	ND	ND	ND	ND
Carbon Tetrachloride	0.23	ND	0.11	0.21	0.13
Chlorobenzene	0.03	ND	ND	0.06	0.07
Chloroethane	0.10	ND	0.21	0.55	1.37
Chloroform	0.07	0.02	0.25	3.21	0.57
Chloromethane	1.60	0.78	1.62	2.21	1.66
Cyclohexane	14.00	0.10	1.10	2.49	0.89
Dibromochloromethane	ND	ND	ND	ND	ND
Dichlorodifluoromethane	1.58	0.71	0.63	0.93	0.68
Ethanol[1]	N/A	N/A	9.86	442.00	5900.00
Ethylbenzene	0.20	ND	0.97	0.29	0.31
Freon 113	0.19	0.09	0.09	0.14	0.10
Freon 114	ND	ND	ND	ND	ND
Hexachloro-1,3-Butadiene	0.12	ND	0.06	ND	0.08
m-Dichlorobenzene	ND	ND	0.09	0.15	0.17
Methanol	N/A	N/A	82.20	54.80	122.00
Methyl t-Butylether	ND	ND	ND	ND	0.13
Methylene Chloride	0.85	2.44	30.30	27.40	19.70
Methylisobutylketone	0.50	ND	0.18	0.12	0.31
n-Heptane	8.80	0.07	1.03	1.32	2.47
n-Hexane	1.50	0.21	2.37	4.28	7.57
o-Dichlorobenzene	ND	ND	0.07	0.09	0.16
o-Xylene	0.21	ND	1.14	0.33	0.32
p-Dichlorobenzene	0.07	ND	0.13	0.15	0.16
p-Ethyltoluene	0.17	ND	0.55	0.26	0.29
Propylene	8.00	2.34	14.30	18.00	32.40
p-Xylene + m-Xylene	0.83	0.08	2.40	0.72	0.74
Styrene	0.21	ND	0.48	0.73	0.65

Compound	**Maximum Measurement (ppb)**				
	Charleroi	**Florence**	**Yonker Site 1**	**Yonker Site 2**	**Yonker Site 3**
t-1,2-Dichloroethylene	ND	ND	ND	ND	ND
t-1,3-Dichloropropene	ND	ND	ND	ND	ND
Tetrachloroethylene	0.40	ND	0.13	0.21	0.07
Tetrahydrofuran	0.86	ND	0.30	0.50	0.40
Toluene	2.76	0.25	68.70	4.27	9.16
Trichloroethylene	0.03	ND	0.07	0.11	ND
Trichlorofluoromethane	0.67	0.33	0.33	0.58	0.38
Vinyl Chloride	ND	ND	ND	0.07	ND

Notes:

ppb = Parts Per Billion; VOC = Volatile Organic Compound.

N/A indicates that there were no measurements of the specified compound, and ND indicates that the compound was not detected.

(1) The maximum ethanol measurements at Site 2 (442 ppb) and Site 3 (5,900 ppb) were recorded on Jun. 9, 2018; the contractor collecting the measurements indicated that on this day, there was potential contamination or impact from nearby mobile off-road emissions sources.

Table A.5 Mean VOC Background Comparisons

Compound	Mean Measurement (ppb)[1]				
	Charleroi	Florence	Yonker Site 1	Yonker Site 2	Yonker Site 3
1,1,1-Trichloroethane	0.03	ND	ND	ND	ND
1,1,2,2-Tetrachloroethane	ND	ND	ND	ND	ND
1,1,2-Trichloroethane	ND	ND	0.03	ND	0.03
1,1-Dichloroethane	ND	ND	ND	ND	ND
1,1-Dichloroethylene	ND	ND	ND	ND	ND
1,2,4-Trichlorobenzene	0.04	ND	0.03	0.03	0.03
1,2,4-Trimethylbenzene	0.03	ND	0.08	0.04	0.04
1,2-Dibromoethane	ND	ND	ND	ND	ND
1,2-Dichloroethane	0.02	0.02	0.03	0.03	0.04
1,2-Dichloropropane	0.02	ND	ND	ND	0.03
1,3,5-Trimethylbenzene	0.02	ND	0.04	0.03	0.03
1,3-Butadiene	ND	ND	0.03	0.03	0.04
1-Bromopropane	0.02	ND	0.03	0.03	ND
2-Butanone	0.61	0.38	0.45	0.54	0.61
2-Hexanone	0.04	ND	0.04	0.05	0.06
Acetone	5.42	4.06	6.01	5.40	5.86
Acrolein	0.42	0.30	0.32	0.40	0.36
Benzene	0.24	0.18	0.13	0.15	0.17
Bromodichloromethane	0.02	ND	ND	ND	ND
Bromoform	ND	ND	ND	ND	ND
Bromomethane	0.03	ND	ND	0.03	0.03
c-1,2-Dichloroethylene	ND	ND	ND	ND	ND
c-1,3-Dichloropropene	ND	ND	ND	ND	ND
Carbon Tetrachloride	0.10	0.10	0.08	0.09	0.08
Chlorobenzene	0.02	ND	ND	0.03	0.03
Chloroethane	0.03	ND	0.04	0.04	0.06
Chloroform	0.02	0.03	0.03	0.07	0.04
Chloromethane	0.57	0.61	0.56	0.57	0.56
Cyclohexane	0.66	0.04	0.06	0.08	0.08
Dibromochloromethane	ND	ND	ND	ND	ND
Dichlorodifluoromethane	0.56	0.59	0.41	0.43	0.42
Ethanol	N/A	N/A	2.19	16.27	73.42
Ethylbenzene	0.03	ND	0.04	0.04	0.04
Freon 113	0.08	0.09	0.07	0.07	0.07
Freon 114	ND	ND	ND	ND	ND
Hexachloro-1,3-Butadiene	0.02	ND	0.03	ND	0.03
m-Dichlorobenzene	ND	ND	0.03	0.03	0.03
Methanol	N/A	N/A	8.44	11.08	13.29
Methyl t-Butylether	ND	ND	ND	ND	0.03
Methylene Chloride	0.10	0.14	0.72	1.15	1.00
Methylisobutylketone	0.03	ND	0.03	0.04	0.04
n-Heptane	0.33	0.02	0.11	0.12	0.14
n-Hexane	0.16	0.08	0.23	0.27	0.31
o-Dichlorobenzene	ND	ND	0.03	0.03	0.03
o-Xylene	0.04	ND	0.05	0.04	0.04
p-Dichlorobenzene	0.02	ND	0.03	0.03	0.03
p-Ethyltoluene	0.02	ND	0.04	0.04	0.03

Compound	Mean Measurement (ppb)[1]				
	Charleroi	Florence	Yonker Site 1	Yonker Site 2	Yonker Site 3
Propylene	1.47	0.96	1.21	1.12	1.33
p-Xylene + m-Xylene	0.10	0.04	0.09	0.08	0.08
Styrene	0.02	ND	0.04	0.07	0.06
t-1,2-Dichloroethylene	ND	ND	ND	ND	ND
t-1,3-Dichloropropene	ND	ND	ND	ND	ND
Tetrachloroethylene	0.04	ND	0.03	0.03	0.03
Tetrahydrofuran	0.03	ND	0.04	0.04	0.04
Toluene	0.37	0.13	1.08	0.25	0.43
Trichloroethylene	0.02	ND	0.03	0.03	ND
Trichlorofluoromethane	0.26	0.27	0.24	0.26	0.25
Vinyl Chloride	ND	ND	ND	0.03	ND

Notes:

ppb = Parts Per Billion; VOC = Volatile Organic Compound.

N/A indicates that there were no measurements of the specified compound, and ND indicates that the compound was not detected.

(1) If at least one measurement at a given site was above detection limit, half of the detection limit was substituted for any measurements below detection limit before calculating the mean.