Final Report

Wando Welch Terminal Air Monitoring Station
Mount Pleasant, South Carolina

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Acronyms and Abbreviations

Arcadis	Arcadis U.S., Inc.
CFR	Code of Federal Regulations
COVID	time intervals occurring during the COVID-19 pandemic
EPA	United States Environmental Protection Agency
ex-COVID	time intervals not occurring during the COVID-19 pandemic
FEM	Federal Equivalent Method
FRM	Federal Reference Method
$\mu g/m^3$	micrograms per cubic meter
NAAQS	National Ambient Air Quality Standards
NO	nitric oxide
NO_2	nitrogen dioxide
NO_X	nitrogen oxides
PM	particulate matter (this air monitoring station and this report focus specifically on $PM_{2.5}$)
$PM_{2.5}$	particulate matter with diameters that are generally 2.5 micrometers and smaller
PM_{10}	particulate matter with diameters that are generally 10 micrometers and smaller
ppb	parts per billion
ppm	parts per million
PTFE	polytetrafluoroethylene
Q	quarter (Q1 is the first quarter of the year)
SCPA	South Carolina Ports Authority
SIP	State Implementation Plan
SO_2	sulfur dioxide
WWT	Wando Welch Terminal

Executive Summary

This report summarizes historical data collected from an air monitoring station at the Wando Welch Terminal in Mt. Pleasant, South Carolina, and presents the results of advanced analytics on that data. The air monitoring station was installed at the terminal in May 2011 by Arcadis U.S., Inc. (Arcadis) and operated continuously through September 2020. The station measured air quality parameters including particulate matter of 2.5 microns or less ($PM_{2.5}$), nitrogen dioxide (NO_2), and sulfur dioxide (SO_2). The station also measured meteorological parameters such as wind speed, wind direction, temperature, relative humidity, and barometric pressure.

Throughout the monitoring period, Arcadis generated quarterly summary reports issued to the South Carolina Ports Authority as well as annual summary reports, which included comparisons of the monitored air quality parameters to their respective National Ambient Air Quality Standard (NAAQS) levels. The South Carolina Ports Authority made these quarterly and annual reports available to the public on its website. $PM_{2.5}$, NO_2, and SO_2 were found to be in compliance with their respective NAAQS levels over the duration of the monitoring period.

This report includes an overview of the history of the air monitoring station, a summary of comparisons to the NAAQS levels presented in the annual reports, and an evaluation of the parameters that may have influenced or otherwise affected $PM_{2.5}$, NO_2, and SO_2 values throughout the monitoring period. Possible influences were assessed through a regression analysis performed on data collected from the monitoring station. The results of the regression analysis are summarized through a series of questions and figures. Logical inferences related to the results of the analytical study are presented but should not be considered definitive as there are many influences on concentrations at the point of measurement including meteorological, time of day, port activity, neighboring sources, and surrounding urban activity.

1 Background

The South Carolina Ports Authority (SCPA) retained Arcadis U.S., Inc. (Arcadis) in late December 2010 to provide continuous air monitoring services at the Wando Welch Terminal (WWT) in Mt. Pleasant, South Carolina. The port is located on the east side of the Wando River and northeast of downtown Charleston as shown on Figure 1.

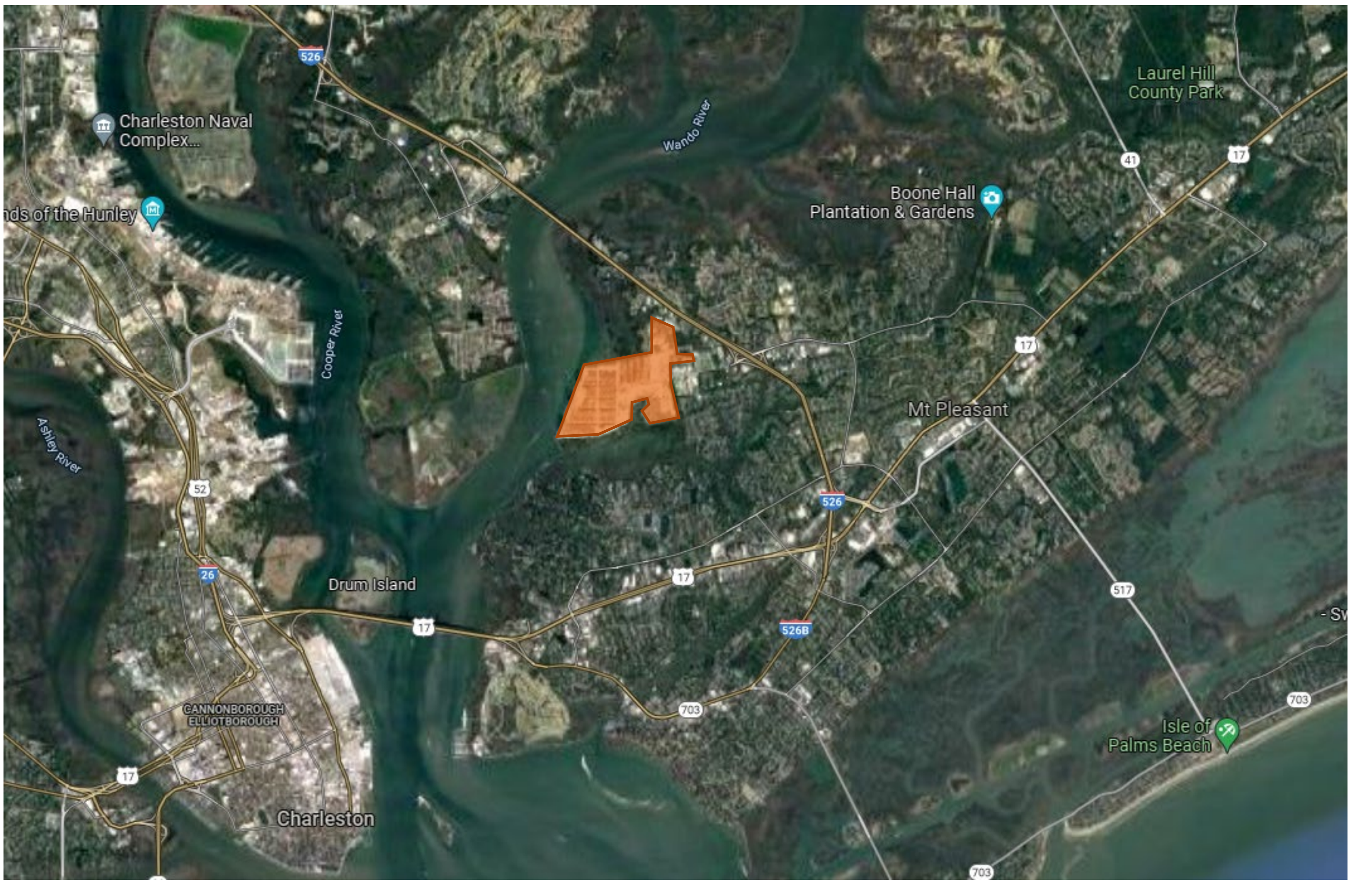


Figure 1. Wando Welch Terminal and Surrounding Area

1.1 History and Overview of the Monitoring Station

Data acquisition commenced on May 6, 2011 in accordance with the court-mandated start date. SCPA requested a system to collect ambient air quality data, including particulate matter less than 2.5 microns ($PM_{2.5}$), sulfur dioxide (SO_2), and nitrogen dioxide (NO_2) levels, for an initial period of five years. The monitoring interval was subsequently extended beyond the initial five-year period and concluded in September 2020.

The air monitoring station was installed on the roof of Building 442 at WWT as shown on Figure 2. The location was central to port activities and along one of the main entry routes for trucks picking up containers after passing through the security checkpoint. This site has proved to be well suited for the evaluation of port activities and related air quality effects. Arcadis maintained the monitoring instruments, stocked consumables such as filters and calibration gases, and ordered spare parts such that downtime was minimized. Arcadis established standard operating procedures to perform daily downloads and to provide Level 1 data validation for the resulting data. Measurements of $PM_{2.5}$, SO_2, and NO_2 were recorded by the monitoring system every 15 seconds, 24 hours per day, 365 days per year during the monitoring program, with limited exceptions resulting from system maintenance, troubleshooting, hardware failure, and calibration.

Figure 2. Air Monitoring Station Location

Meteorological parameters such as wind speed, wind direction, temperature, relative humidity, and atmospheric pressure were also collected every 15 seconds during the monitoring period. During the approximately 10-year operating period, Arcadis developed quarterly reports summarizing the results generated from the air monitoring station for comparison to applicable National Ambient Air Quality Standards (NAAQS), which are included in Section 1.2 for the monitored pollutants. The air monitoring project proved to be reliable and generated valid, high-quality data suitable for use in dispersion modeling or other potential purposes.

The instruments that formed the basis of the continuous air monitoring station at WWT are indicated in Table 1. Compliance with pertinent NAAQS $PM_{2.5}$, SO_2, and NO_2 requires the use of United States Environmental Protection Agency (EPA) Federal Reference Methods (FRMs) or Federal Equivalent Methods (FEMs) for the quantification of these pollutants in the engineering units necessary for comparison to the standards. The applicable FRM requirements for the measurement of these pollutants are detailed in the appendices of 40 Code of Federal Regulations (CFR) Part 50. Instrument vendors can obtain FRM/FEM designation for their instrumentation through the use of the validation procedures detailed in 40 CFR Part 53.

Table 1. Instrumentation of the Wando Welch Terminal Continuous Air Monitoring Station

Instrument Model	Description
Thermo Scientific Model 5014i-ABVAC	EPA FRM $PM_{2.5}$ Particulate Sampler
Thermo Scientific Model 43i-ANSAA	SO_2 Analyzer
Thermo Scientific Model 42i-ANMSPAA	NO-NO_2-NO_X Analyzer
Thermo Scientific Model 146i-AT3BEAA	Dynamic Gas Calibrator
Thermo Scientific Model 1160-AHP2N	Zero Air Supply
Vaisala Model WXT520	Meteorological System

Particulate Monitor

The FRM for $PM_{2.5}$ is described in *Appendix L to Part 50—Reference Method for the Determination of Fine Particulate Matter as $PM_{2.5}$ Atmosphere.* In this method, an electrically powered air sampler draws ambient air at a constant volumetric rate into a specially shaped inlet and through an inertial impactor where particulate matter (PM) in the $PM_{2.5}$ size range is separated for collection on a polytetrafluoroethylene (PTFE) filter over the specified sampling period. The $PM_{2.5}$ particulate concentration in the atmosphere is calculated from the weight gained on the PTFE filter ($PM_{2.5}$ mass) and the total volume of ambient air sampled (corrected to standard conditions).

A Thermo Scientific Model 5014i-ABVAC Continuous Ambient Particle Monitor was used for the continuous measurement of $PM_{2.5}$ at WWT. This device, when equipped with a PM_{10} size selective inlet and a Bob Gussman Instruments (BGI) $PM_{2.5}$ Very Sharp Cut Cyclone, is an automated version of the reference method described above and has achieved the equivalency designation. It uses the principle of beta attenuation to continuously measure $PM_{2.5}$ particulate. Its Automated Equivalent Method Designation is EQPM-0609-183.

Sulfur Dioxide Monitor

The FRM for SO_2 is described in *Appendix A to Part 50—Reference Method for the Determination of Sulfur Dioxide in the Atmosphere (Pararosaniline Method).* This method involves a manual procedure that requires bubbling an ambient air sample through impingers containing potassium tetrachloromercurate and complex spectrophotometric analytical procedures. It has been largely supplanted by FEMs in practical usage.

A Thermo Scientific Model 43i SO_2 Analyzer, which has been designated as an FRM using the 40 CFR Part 53 procedure, was used for the continuous measurement of SO_2 at WWT. This continuous monitor uses the principle of pulsed fluorescence and has an Automated Equivalent Method Designation of EQSA-0486-060.

Nitrogen Oxide/Nitrogen Dioxide Monitor

The FRM for NO_2 is detailed in *Appendix F to Part 50—Measurement Principle and Calibration Procedure for the Measurement of Nitrogen Dioxide in the Atmosphere (Gas Phase Chemiluminescence).* In this procedure, atmospheric concentrations of NO_2 are measured indirectly by photometrically measuring the light intensity at wavelengths greater than 600 nanometers resulting from the chemiluminescent reaction of nitric oxide (NO) with ozone (O_3). NO_2 is first reduced to NO with a converter. NO, which commonly exists in ambient air together with NO_2, passes through the converter unchanged, causing a resultant total oxides of nitrogen (NO_X) concentration equal to NO+NO_2. A sample of the ambient air is also measured without having passed through the converter. This latter measurement (NO) is subtracted from the former measurement (NO_X) to yield NO_2. The NO and NO_X

measurements may be made concurrently with dual chemiluminescent analyzer systems, or cyclically with the same system as long as the cycle time does not exceed 1 minute.

A Thermo Scientific Model 42i NO-NO_2-NO_X Analyzer, which has been designated as an FRM, was used for the continuous measurement of NO_2 at WWT. This continuous analyzer uses the chemiluminescence principle required of an NO_2 FRM; it uses the cyclic approach to NO_2 determination. Its Automated Reference Method Designation is RFNA-1289-074.

Gas Dilution System/Calibrator

A Thermo Scientific Model 146i-AT3BEAA Dynamic Gas Calibrator was used to generate calibration and span gas concentrations from certified cylinders of SO_2 and NO. It uses high-accuracy mass flow controllers to blend zero air from the Thermo Scientific Model 1160-AHP2N Zero Air Supply with known concentrations of SO_2 and NO from the cylinders to produce a precise, part-per-billion (ppb) concentration of these gases to calibrate and zero/span check the instruments to ensure accuracy. The 146i calibrator also has an integral ozonator for use in calculating the NO_2 coefficient used by the 42i NO_X instrument.

Meteorological System and Sensors

A Vaisala WXT520 weather transmitter was installed to continuously measure the following parameters at the air monitoring station:

- Wind Speed
- Wind Direction
- Relative Humidity
- Temperature
- Barometric Pressure
- Precipitation

1.2 Comparison to NAAQS

One of the objectives of the project was to provide continuous determination of $PM_{2.5}$, SO_2, and NO_2 ambient concentrations at WWT to demonstrate compliance with the NAAQS for these parameters. These standards are identified in Table 2. The Clean Air Act requires EPA to set NAAQS levels for principal pollutants, which include $PM_{2.5}$, SO_2, and NO_2, that can be harmful to public health and the environment. The Clean Air Act identifies two types of NAAQS. Primary standards provide public health protection, including protecting the health of sensitive populations such as asthmatics, children, and the elderly. Secondary standards provide public welfare protection, including protection against decreased visibility and damage to animals, crops, vegetation, and buildings.

Table 2. NAAQS References

Pollutant	Primary/ Secondary	Averaging Time	Level	Form
NO_2	Primary	1-hour	100 ppb	98th percentile, averaged over 3 years
	Primary and Secondary	Annual	53 ppb (1)	Annual mean
SO_2	Primary	1-hour	75 ppb (2)	99th percentile of 1-hour daily maximum concentrations, averaged over 3 years
	Secondary	3-hour	0.5 ppm	Not to be exceeded more than once per year
$PM_{2.5}$	Primary	Annual	12 µg/m^3	Annual mean, averaged over 3 years
	Secondary	Annual	15 µg/m^3	Annual mean, averaged over 3 years
	Primary and Secondary	24-hour	35 µg/m^3	98th percentile, averaged over 3 years

Notes:

(1) The level of the annual NO_2 standard is 0.053 ppm. It is shown here in terms of ppb for the purposes of clearer comparison to the 1-hour standard level.

(2) The previous SO_2 standards (0.14 ppm 24-hour and 0.03 ppm annual) additionally remain in effect in certain areas: (1) any area for which it is not yet 1 year since the effective date of designation under the current (2010) standards, and (2) any area for which an implementation plan providing for attainment of the current (2010) standards has not been submitted and approved and which is designated nonattainment under the previous SO_2 standards or is not meeting the requirements of a State Implementation Plan (SIP) call under the previous SO_2 standards (40 CFR 50.4(3)). An SIP call is an EPA action requiring a state to resubmit all or part of its State Implementation Plan to demonstrate attainment of the required NAAQS.

µg/m^3 = micrograms per cubic meter
ppm = parts per million

Quarterly and annual summary reports for the WWT air monitoring station have been issued and released on SCPA's website since the monitoring program began in May 2011. The annual summary reports provide comparisons to the NAAQS parameters identified in Table 2 above. The results presented within these annual reports are summarized in Table 3. Certain criteria, as detailed in the NAAQS overview table (Table 2), require three years of data to form the basis of calculation and comparison to NAAQS values. These instances are noted in Table 3 where applicable. In certain instances where the criterion is based on a three-year average, but three years of data were not yet available, the one-year average result for that parameter was included for reference in the annual summary report although it is not directly applicable. These instances are identified with a footnote in Table 3. Since the start of the ambient air monitoring program at WWT in the second quarter of 2011 through the final annual summary report issued following the first quarter of 2020, all monitored pollutants were in compliance with their respective NAAQS levels. Comparisons of pollutant levels to the NAAQS from second quarter 2011 through first quarter 2020 are shown on the graphs presented as Figure 3 (NO_2), Figure 4 (SO_2), and Figure 5 ($PM_{2.5}$).

Table 3. Wando Welch Terminal NAAQS Comparison Overview

Pollutant:	NO_2		SO_2		$PM_{2.5}$		
Primary/ Secondary:	Primary	Primary and Secondary	Primary	Secondary	Primary	Secondary	Primary and Secondary
Averaging Time:	1 hour	1 year	1 hour	3 hours	1 year	1 year	24 hours
NAAQS Level:	100 ppb	53 ppb	75 ppb	0.5 ppm (500 ppb)	12.0 µg/m^3	15.0 µg/m^3	35.0 µg/m^3
Form:	98th percentile of 1-hour daily maximum concentrations, averaged over 3 years	Annual mean	99th percentile of 1-hour daily maximum concentrations, averaged over 3 years	Not to be exceeded more than once per year	Annual mean, averaged over 3 years	Annual mean, averaged over 3 years	98th percentile, averaged over 3 years
Monitoring Interval	ppb	ppb	ppb	ppb	µg/m^3	µg/m^3	µg/m^3
Q2 2011 - Q1 2012	N/A	7	N/A	*	11.2^	11.2^	N/A
Q2 2012 - Q1 2013	N/A	8	N/A	*	10.1^	10.1^	N/A
Q2 2013 - Q1 2014	26	8	33	*	10.3	10.3	23
Q2 2014 - Q1 2015	46	9	17	2.32**	9.7	9.7	19
Q2 2015 - Q1 2016	39	8	9	0.87	9.3	9.3	18
Q2 2016 - Q1 2017	31	9	5	0.73	9.6	9.6	20
Q2 2017 - Q1 2018	51	9	4	0.85	10.5	10.5	27
Q2 2018 - Q1 2019	55	10	4	3.06	11.1	11.1	33
Q2 2019 - Q1 2020	51	9	4	4.18	10.8	10.8	31

Notes:

*	3-hour averages were not calculated. However, the 1-hour average maximum from Q2 2011 through Q1 2014 was only 67 ppb.
**	Maximum since July 2014, values not calculated prior to this time.
^	Annual mean for that year, three years of data not yet available.
N/A	Not applicable, parameter requires three years of data to calculate.
Q1	Quarter 1
Q2	Quarter 2

The WWT air monitoring station was decommissioned in September 2020. SCPA then requested a detailed investigation into factors that may have influenced ambient concentrations of $PM_{2.5}$, SO_2, and NO_2. These factors include wind speed, wind direction, port activity, time of day, holidays, and any influences relating to the COVID-19 pandemic. Ambient air quality data and meteorological data generated during operation of the ambient air monitoring station from May 2011 through September 2020 were processed for incorporation into a Power BI database. SCPA provided port traffic data for incorporation into this database. These data were then used to create a custom Power BI dashboard, which allows the user to study how one or more variables impact another. For example, the user is able to determine if wind speed and/or direction had an influence on ambient air concentrations of $PM_{2.5}$, SO_2, or NO_2. The conclusions of this investigation are presented in the subsequent sections of this report.

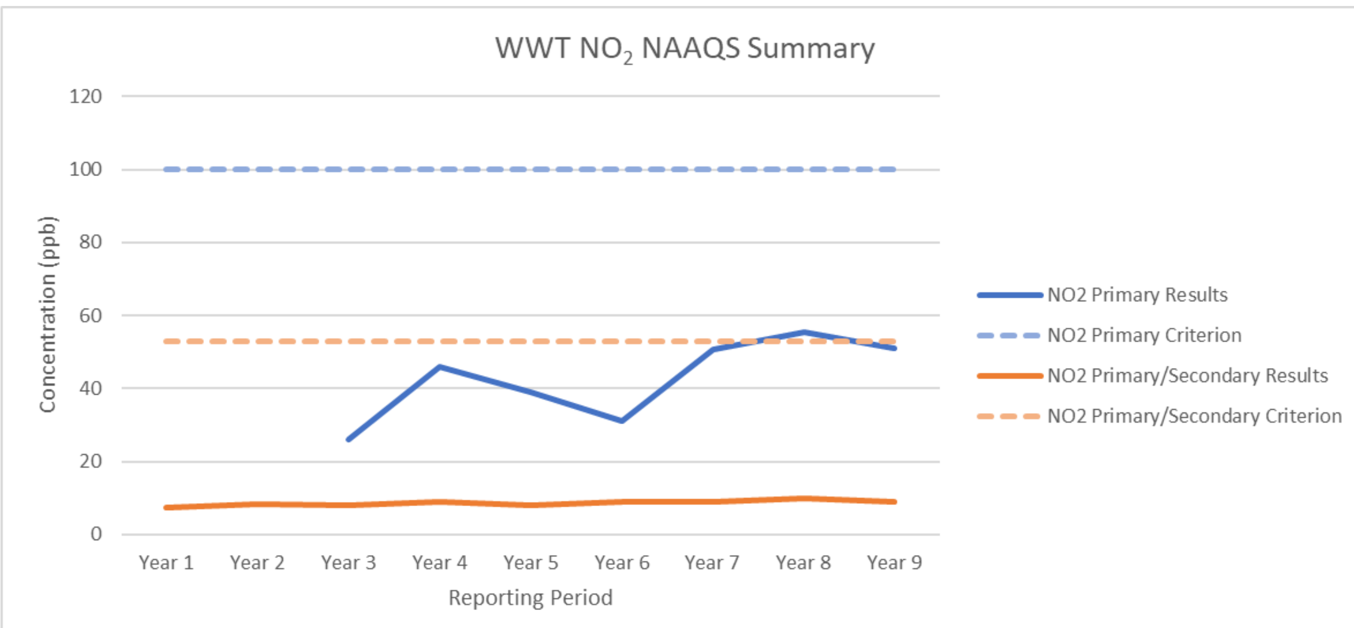


Figure 3. NO_2 NAAQS Comparison

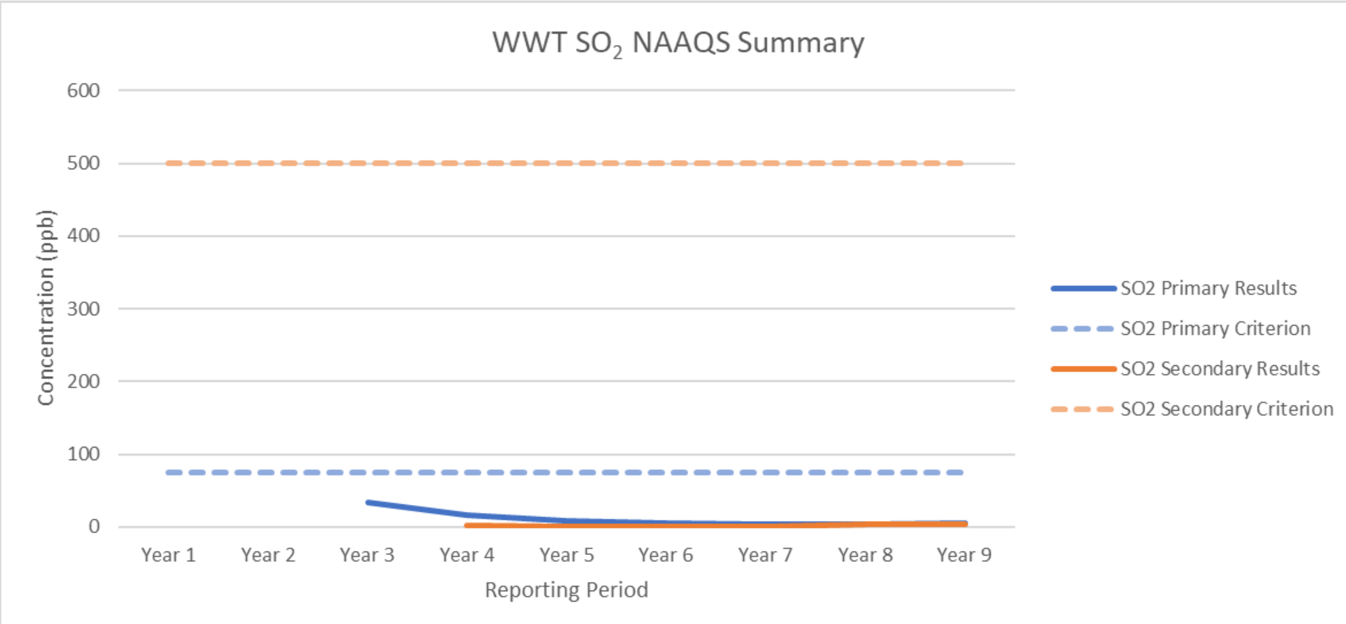


Figure 4. SO_2 NAAQS Comparison

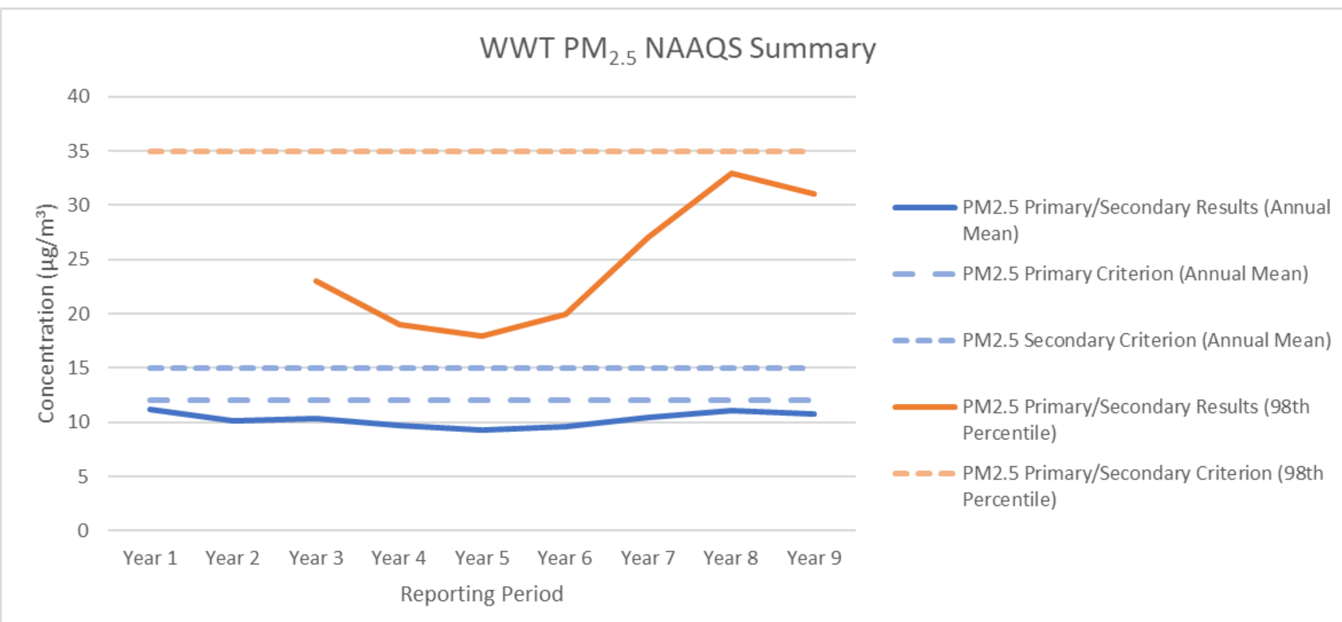


Figure 5. $PM_{2.5}$ NAAQS Comparison

2 Evaluation of Potential Influencers

Arcadis evaluated the impacts of four potential influencers on the air quality at the port facility:

- Time – impacts related to the time of day and whether the port was open or closed (e.g., workdays, weekends, and holidays)
- Weather – impacts related to wind, temperature, humidity, and barometric pressure

- Port Activity Level – impacts related to ship and container volume processed by the port
- COVID – impacts related to the pandemic

A regression analysis was performed on the data to determine the level of impact of each influencer on measured concentrations. Figure 6 is a typical illustration of the output from the regression analysis, i.e., how different factors (key influencers) contribute to an increase in concentration. The numbers are displayed in the units of the measured concentrations. NO_2 and SO_2 are measured in ppb, while $PM_{2.5}$ is measured in μg/m^3. In the example shown on Figure 6, the largest influencer of NO_2 concentrations is time of day. Between 6:00 a.m. and 9:00 a.m., the average NO_2 concentration typically increases by 8.48 ppb. The second largest influencer is whether the day in question is a *non*-holiday, whereby NO_2 typically increases by 5.83 ppb. This same method of illustration was used to summarize key influencers for $PM_{2.5}$ and SO_2.

Additional information on this and other dashboard elements and tools is provided in Section 5 – Background and Data Development.

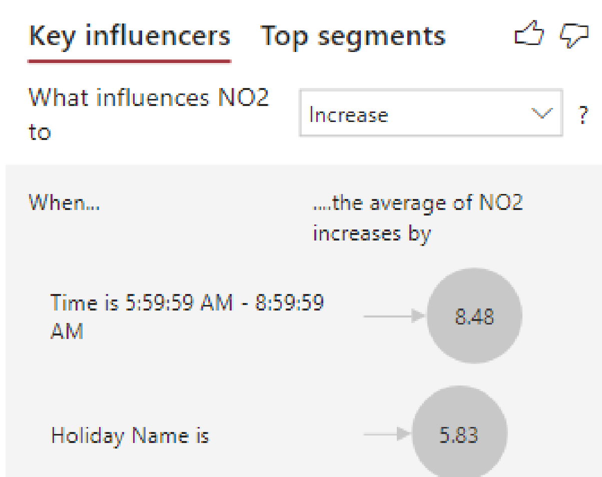


Figure 6. Key Influencers

2.1 Time

For this category of influencers, three factors were evaluated:

- Time of day (hourly)
- Weekday/Weekend
- Holidays

Figure 7 summarizes the impacts of time for NO_2, $PM_{2.5}$, and SO_2 (left to right).

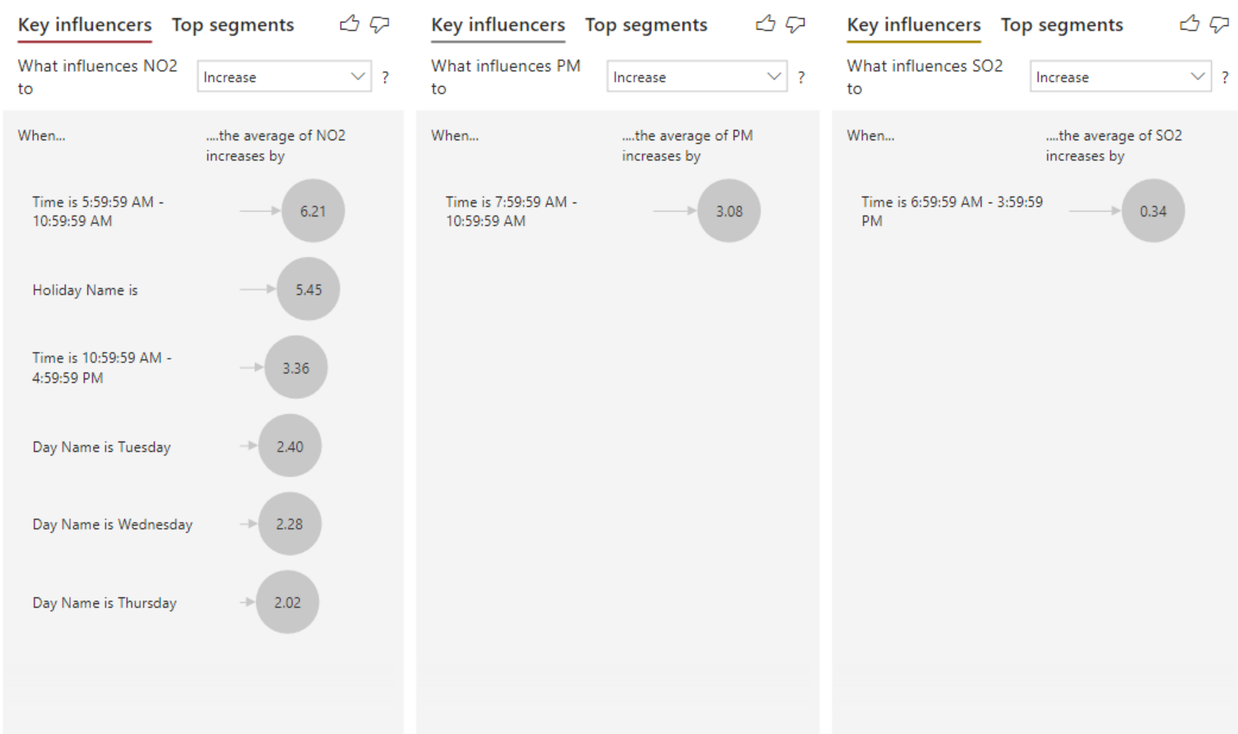


Figure 7. Time Influencers

To compare the relative impacts across the three pollutants, it helps to refer to the overall averages of each during the recording period. These averages were:

- NO_2: 6.84 ppb
- $PM_{2.5}$: 8.60 µg/m^3
- SO_2: 0.105 ppb

As Figure 7 illustrates, the key influencer for NO_2 is time of day, with the periods of 6:00 to 11:00 a.m. and 11:00 a.m. to 5:00 p.m. resulting in average concentration increases of 6.21 and 3.36 ppb, respectively. Non-holidays are also a key influencer, along with the mid-week workdays (Tuesday, Wednesday, and Thursday). Impacts to $PM_{2.5}$ and SO_2 are limited to time of day. The impact on $PM_{2.5}$ (increase of 3.08 µg/m^3) is less in terms of percentage. The impact on SO_2 (increase of 0.34 ppb) is more pronounced, more than double the average value, although concentrations are consistently very low throughout the monitoring period.

Time of day influences concentrations more than any other factor. Figure 8 illustrates the influence on average hourly concentrations for NO_2, $PM_{2.5}$, and SO_2 over the recording period for each hour of the day. Figure 8 shows the increases in concentrations due to increased activity at the port and in the surrounding community during normal working hours. This figure is not based on the number of containers moved or the number of ships in port.

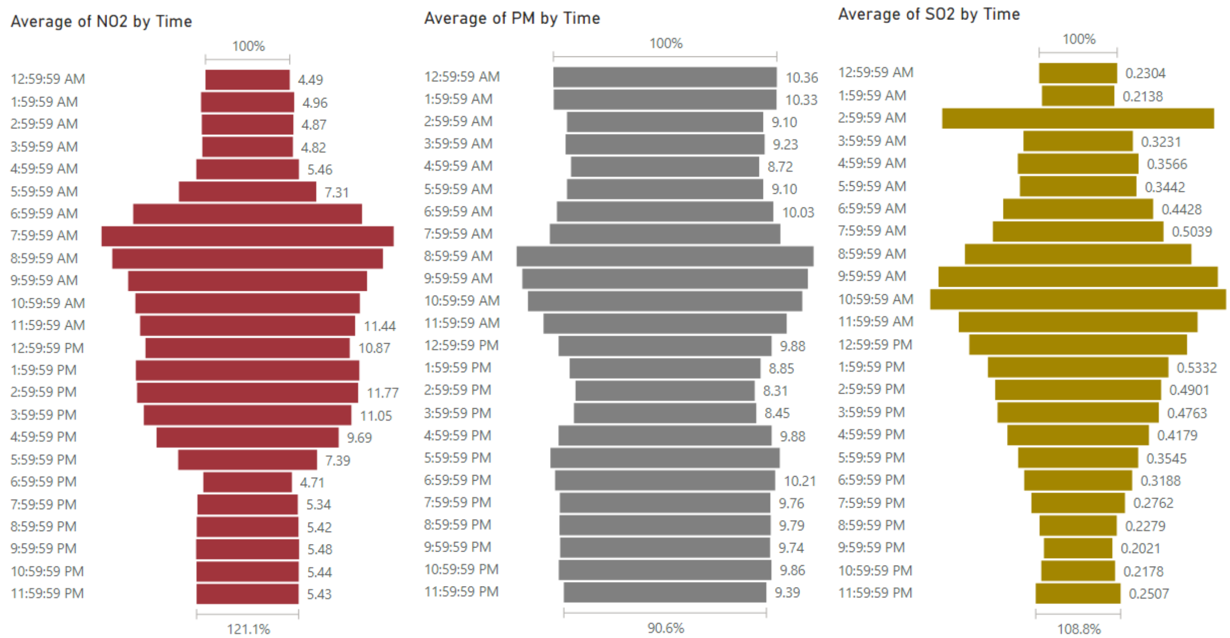


Figure 8. Time-of-Day Averages

NO_2 experiences the highest time-of-day influence, with concentrations clearly increased during typical working hours. A similar conclusion can be made for SO_2, although the increase is less pronounced than for NO_2. $PM_{2.5}$ is less suceptibile to time-of-day influences. Of particular note is the SO_2 concentration at 3:00 a.m. At this time each day, the monitoring system undergoes a quality check process and a small amount of residual SO_2 is carried over in the sampling lines even after purging with clean air.

2.2 Weather

Five factors were evaluated related to weather:

- Wind Speed (meters per second)
- Wind Direction – Per EPA guidance, the analysis does not consider wind direction at wind speeds of less than 0.5 meters per second. Wind was separated into eight major vectors, consistent with normal wind direction nomenclature (north, northeast, etc.).
- Temperature (degrees Celsius)
- Relative Humidity (%)
- Barometric Pressure (millibars)

Figure 9 illustrates a number of key weather-related influencers for NO_2, $PM_{2.5}$ and SO_2. The following generalized observations can be made:

- For NO_2 and SO_2, concentrations increase when the wind is from the west or northwest.
- For all three pollutants, concentrations increase when the wind speed is low.
- For $PM_{2.5}$, temperature is the primary influencer.

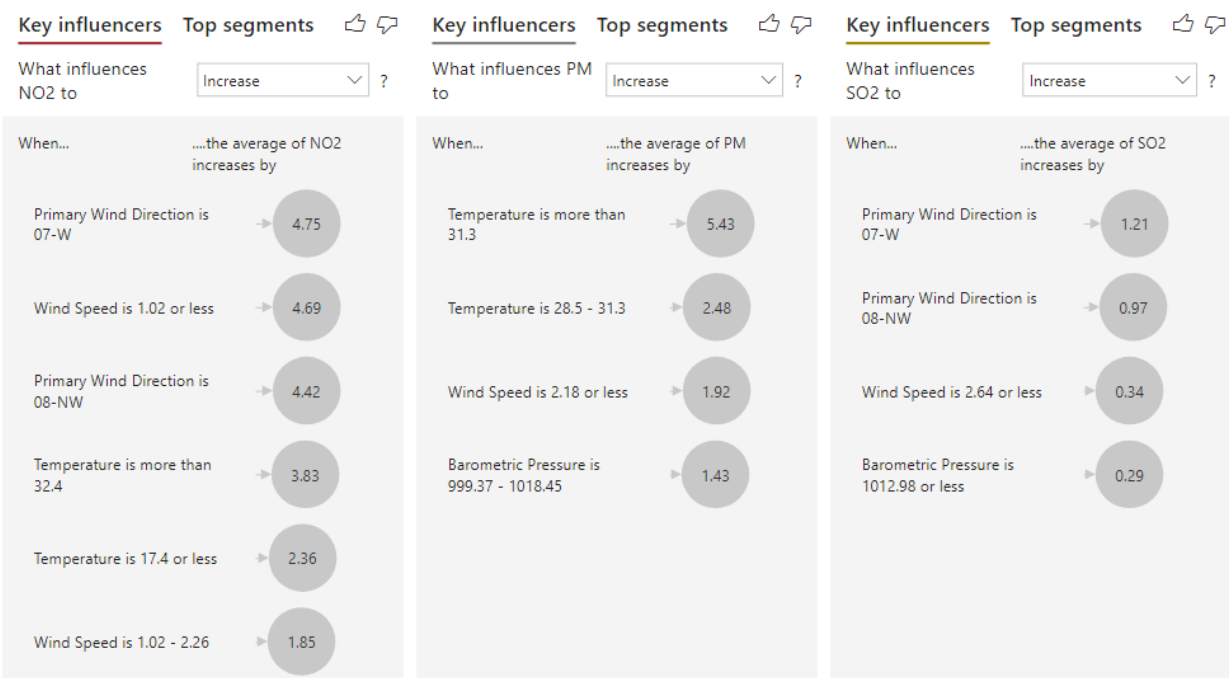


Figure 9. Weather Influencers

2.3 Port Activity

Port activity data were provided by SCPA and included:

- Container Volume
- Ship Traffic (the maximum number of ships docked at the facility on any given day)

As Figure 10 illustrates, NO_2 and SO_2 are only slightly influenced by port activity. It should be noted that the NO_2 impact (2.12 ppb) is less significant than that caused by the leading influencers: time of day (6.21 ppb from 6:00 to 11:00 a.m.) and wind direction (4.75 ppb when from the north). SO_2 is also less impacted by port activity than it is by time of day and wind direction.

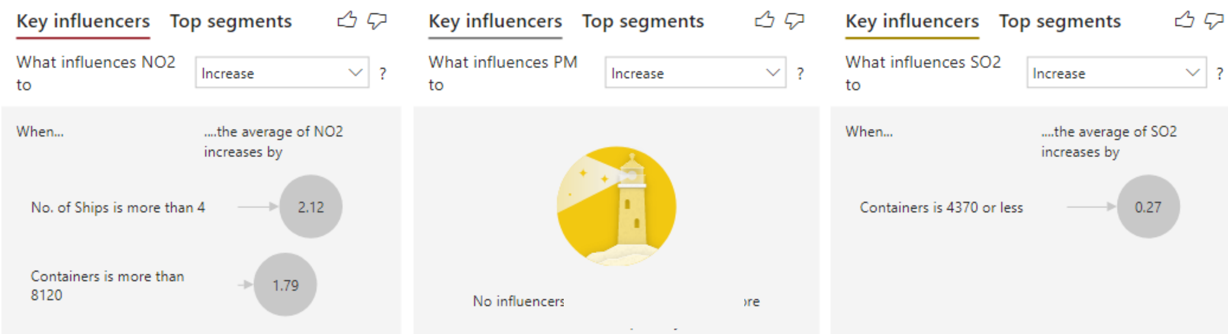


Figure 10. Port Authority Influencers

2.4 COVID

The analysis of impacts related to the COVID pandemic was limited by the following factors:

- An instrumentation failure occurred near the onset of the COVID pandemic in the winter of 2020. Between February 25, 2020 and July 13, 2020, the monitoring system failed to provide data for NO_2 and SO_2. Supply chain issues brought about by COVID delayed the receipt and installation of the equipment necessary to remedy the NO_2 and SO_2 data acquisition issues until July 2020. However, data for $PM_{2.5}$ were available during the entire period.
- Operation of the monitoring system was discontinued on September 3, 2020.

Because of the potential for variability in concentrations seasonally, Arcadis performed a comparison of COVID and non-COVID impacts for similar months of the year, in this case July through August. The results are shown on Figure 11.

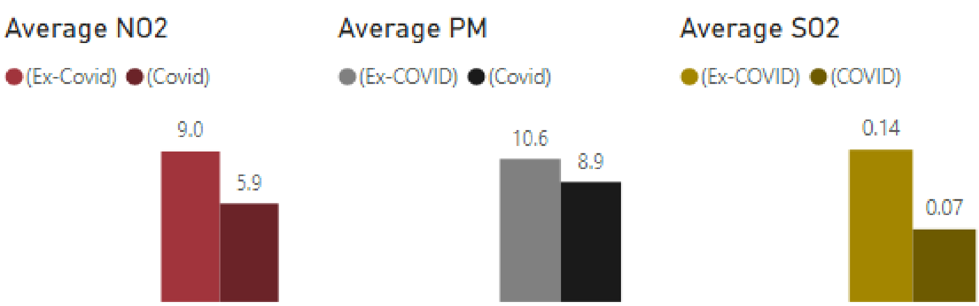


Figure 11. COVID Impacts

It should be noted that while port operations in the first half of 2020 were significantly lower than typical, operations in the latter half of the year rebounded dramatically, resulting in an annual record of container volume. Much of this period of increased volume occurred after monitoring had ceased at WWT.

Additional details on each of the influencers discussed in Sections 2.1 through 2.4 are provided in Section 3.

3 Analysis Questions and Answers

SCPA's scope of work included specific questions to be addressed in this report. These questions include:

1. Under similar wind conditions, how are concentrations impacted by the level of activity at the port?
2. Under similar wind conditions, how do concentrations compare on holidays (limited truck traffic at the port)?
3. Are daytime concentrations higher with wind coming from the direction of the river?
4. How much lower are the concentrations when the wind is coming from the direction opposite the river?
5. With wind from the river, how does container activity impact emissions?
6. With wind from the river, how does the number of ships in port impact emissions?
7. How does wind direction and/or speed influence concentrations?
8. Are there any significant differences in the data for March 2020 through the COVID pandemic? (This analysis is limited to $PM_{2.5}$ data due to a calibration instrument failure at WWT.)

3.1 Question 1

Under similar wind conditions, how are concentrations impacted by the level of activity at the port?

This analysis was restricted to the middle 50 percent of typical average wind speeds for Charleston (2.23 to 5.36 meters per second). Figure 12 illustrates the impacts of NO_2 under those conditions.

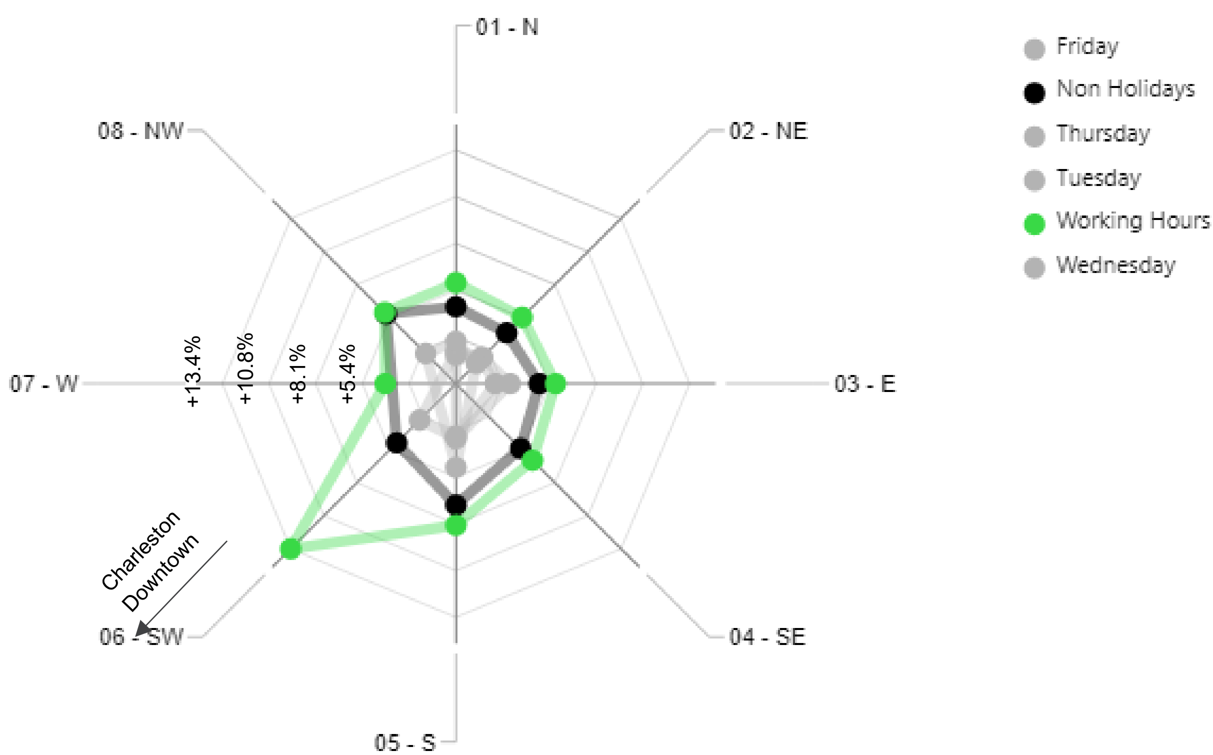


Figure 12. Percentage Influence on Air Quality Under Similar Wind Conditions

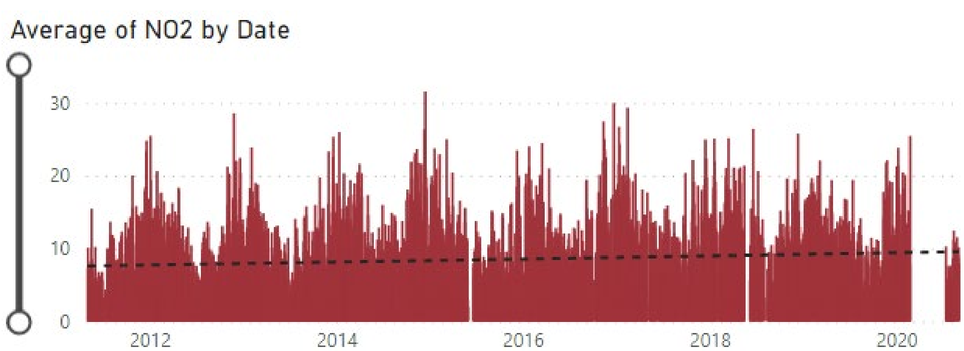
The data presented on Figure 12 fall into one of three scenarios:

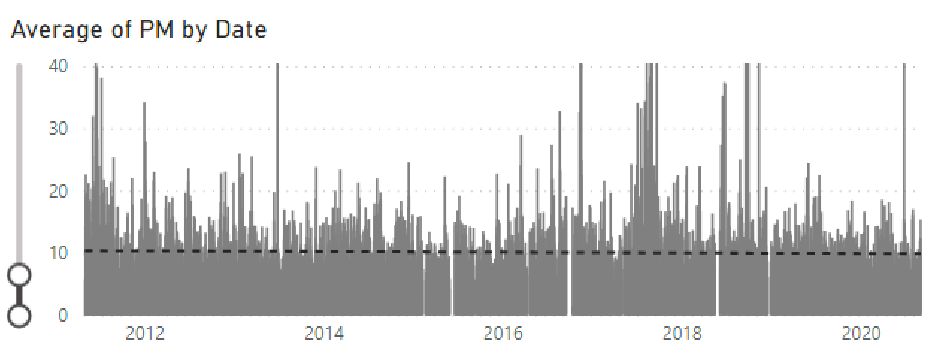
- Scenario 1: Working Hours – Represented by the green ring, this scenario represents a potential 'worst-case' situation: both an active port and an active working community. The greatest impact to air quality occurs in this scenario. Of significance is a noticeable spike in concentrations when winds are from the southwest, i.e., from downtown Charleston.
- Scenario 2: Non-Holidays – Represented by the black ring, this scenario represents a slightly less intensive situation: the port and the community are active, but impacts are spread out over 24 hours. Lower concentrations during non-working hours both on the part of the port and the community result in a reduced impact relative to Scenario 1.
- Scenario 3: Tuesday through Thursday – Represented by the series of gray rings, this scenario is similar to Scenario 2, except that it excludes weekends. Because concentrations in this scenario are lower than those measured in Scenario 2, it can be concluded that weekend concentrations (community-only) are more significant than weekday concentrations when the port is in operation.

In each case, the overall conclusion of this analysis is that contributions from community activity have a greater impact on air quality when compared to port operations.

3.1.1 Trends Over Time

Since monitoring began, overall daily average concentrations for NO_2 have increased slightly. $PM_{2.5}$ concentrations have remained almost stable, while SO_2 concentrations have declined significantly. Figure 13 illustrates these trends for NO_2, $PM_{2.5}$, and SO_2.





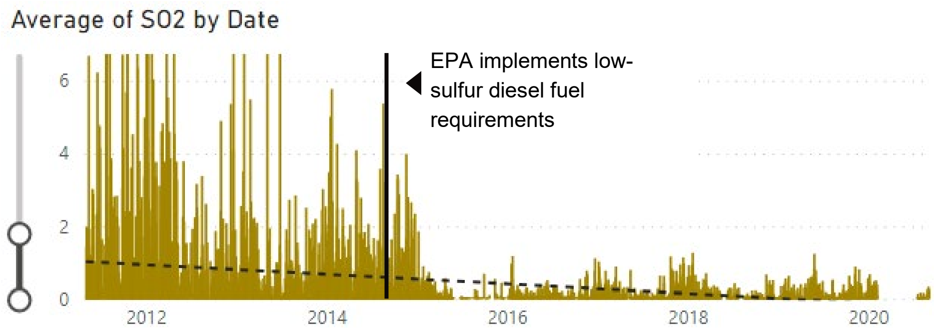


Figure 13. Trends Over Time

There is a sharp decrease in SO_2 concentrations around 2015. This decrease coincides with implementation of EPA rules requiring the use of low-sulfur diesel fuel, which were fully implemented by the end of 2014.

3.1.2 Five-Year Trends

The five-year trends for NO_2 and $PM_{2.5}$ indicate an overall decline in concentrations as shown on Figure 14.

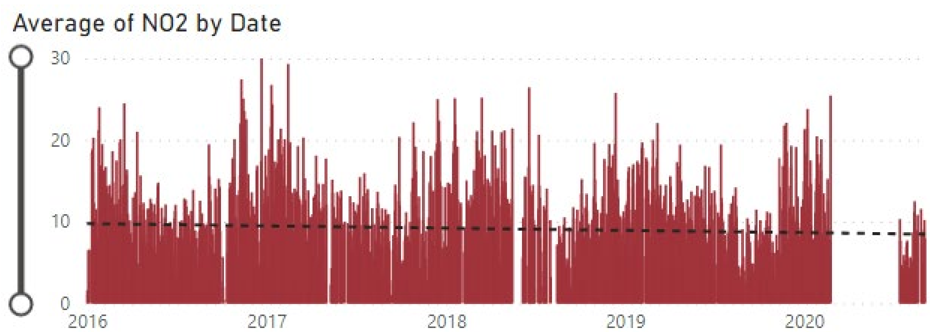


Figure 14. Five-Year Trends

3.2 Question 2

Under similar wind conditions, how do concentrations compare on holidays (limited truck traffic at the port)?

Figure 15 shows holiday concentrations under similar wind conditions and illustrates that port operations and community workday activities have a measurable impact on NO_2. $PM_{2.5}$ and SO_2 are influenced less. A unique observation involves $PM_{2.5}$, where Independence Day concentrations are higher than those observed during normal port and community activity. These elevated levels are believed to be attributed to fireworks in Charleston and surrounding areas.

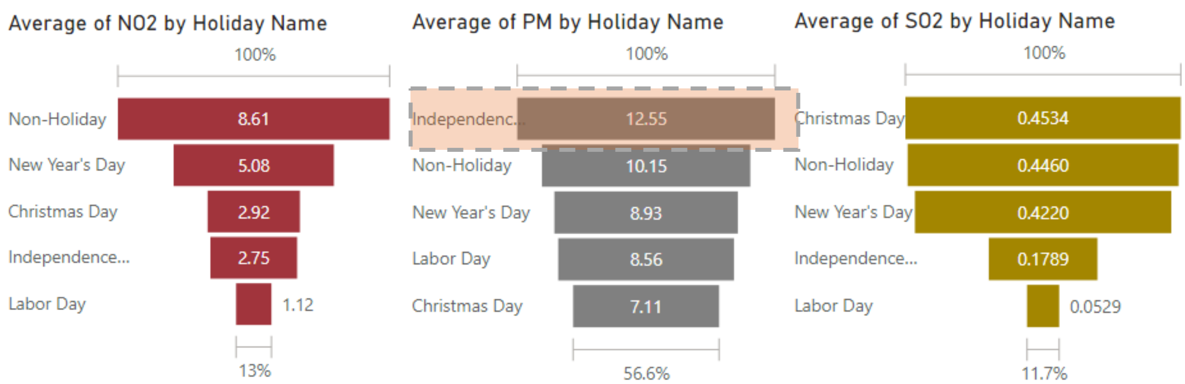


Figure 15. Holiday Concentrations vs. Non-Holiday

3.3 Questions 3 and 4

Are daytime concentrations higher with wind coming from the direction of the river?

How much lower are the concentrations when the wind is coming from the direction opposite the river?

Figure 16 shows changes in concentrations based on wind direction.

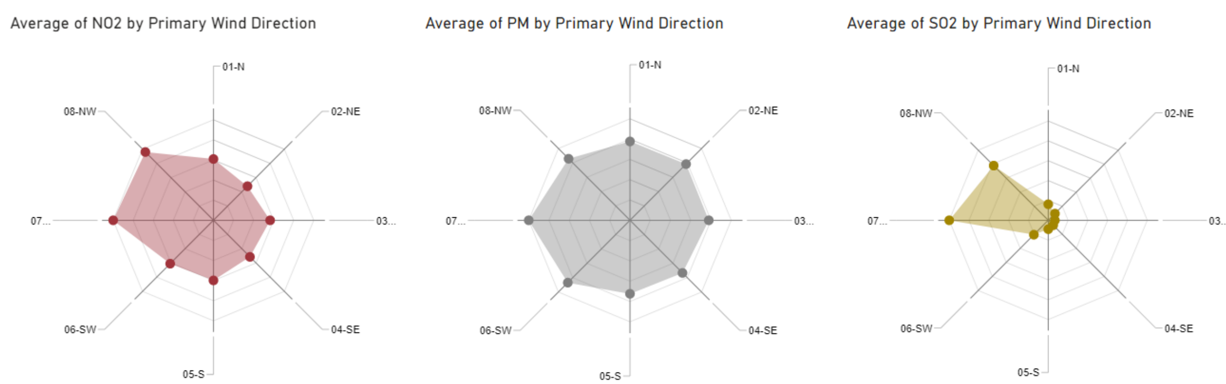


Figure 16. Concentrations Versus Wind Direction

NO_2 concentrations are impacted when wind is from the river (west and northwest). PM concentrations are much less impacted, with almost no impact other than when winds are directly from the west. SO_2 shows the highest differential with respect to wind direction, although the values are very low, nearing the limits of detectability.

The WWT air monitoring station was positioned near the entrance to the container yard. This location was along the centerline of the container yard and associated activity. Farther to the west of the port is North Charleston. To the northwest of the port is the I-26 corridor. The elevated concentrations when wind is from the west and northwest can likely be attributed to port activity and the populated areas west and northwest of WWT.

It should be noted that the values shown on Figure 16 consider all wind speeds greater than 0.5 meters per second. As shown on Figure 12, when wind is limited to more typical velocities (the middle 50 percent), the greatest impact occurs to NO_2 concentrations. The NO_2 concentration more than doubles when winds are from the southwest (i.e., the general direction of the metropolitan Charleston area).

3.4 Questions 5 and 6

With wind from the river, how does container activity impact emissions?

With wind from the river, how does the number of ships in port impact emissions?

For purposes of this analysis, wind direction was limited to the west and northwest. As shown on Figure 17, the greatest impact to NO_2 was a 3.26 percent increase when four or more ships were in port on any given day. Findings were similar for $PM_{2.5}$.

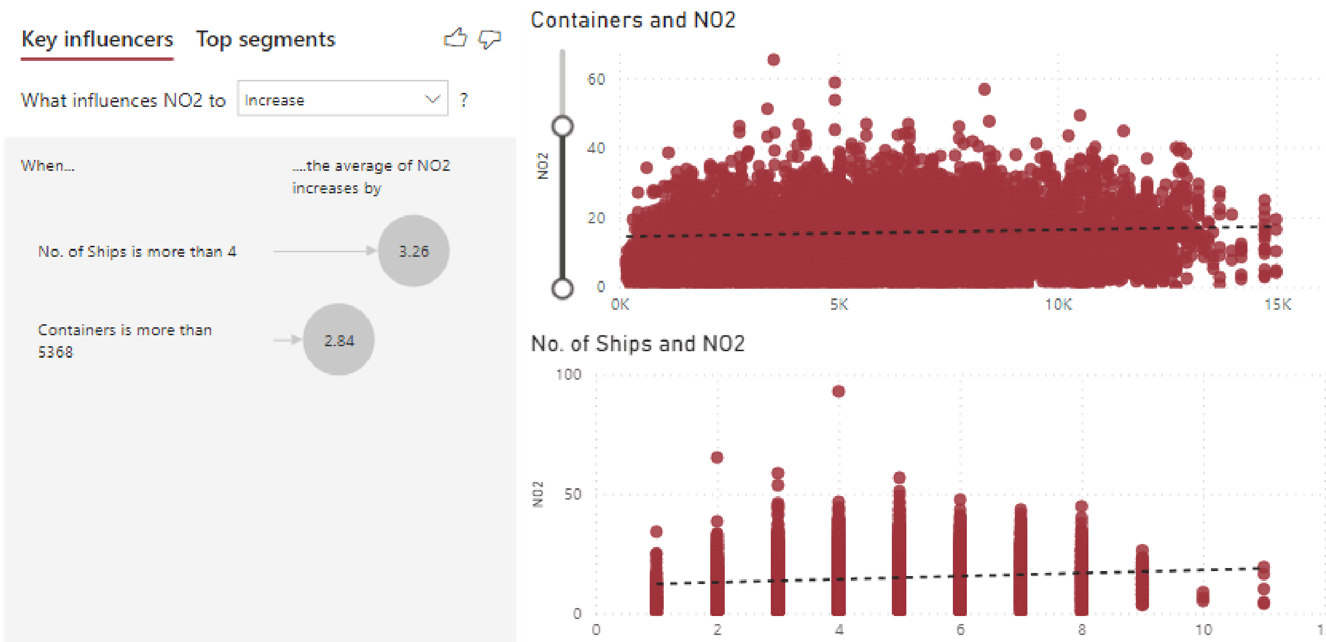


Figure 17. Container and Ship Activity Impacts on NO_2 When Wind is From the River

Figure 18 shows a 1.17 percent increase in the SO_2 concentration when container volume is in the range of 777 to 4,288 per day. Of interest is that higher levels of container traffic (4,289+) show no discernible relationship with SO_2 concentration in this scenario. This analysis and graphic show persistently low SO_2 levels at WWT.

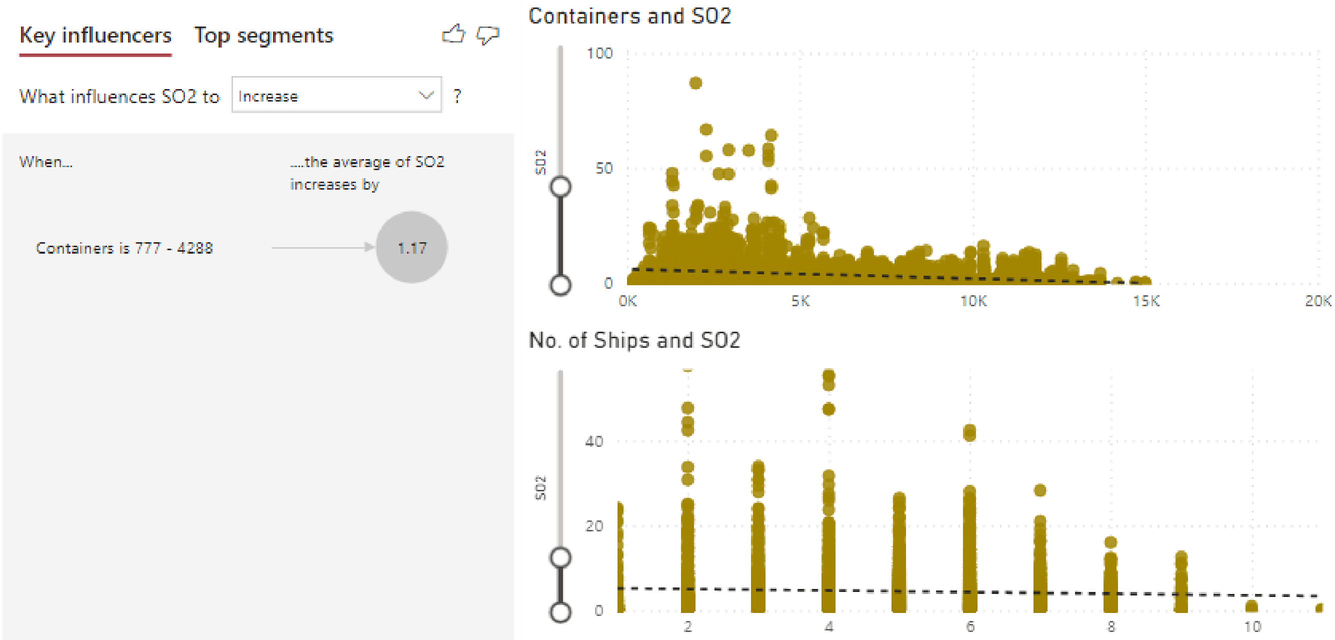


Figure 18. Container and Ship Activity Impacts on SO_2 When Wind is From the River

3.5 Question 7

How does wind direction and/or speed influence concentrations?

As noted previously, wind direction plays a significant role in the pollutant concentrations. Per EPA guidance, Arcadis' analysis only considered impacts when wind speed is greater than 0.5 meters per second. Lower wind speeds tend to be directionally unstable. Figure 19 illustrates the impacts of wind speed on concentrations.

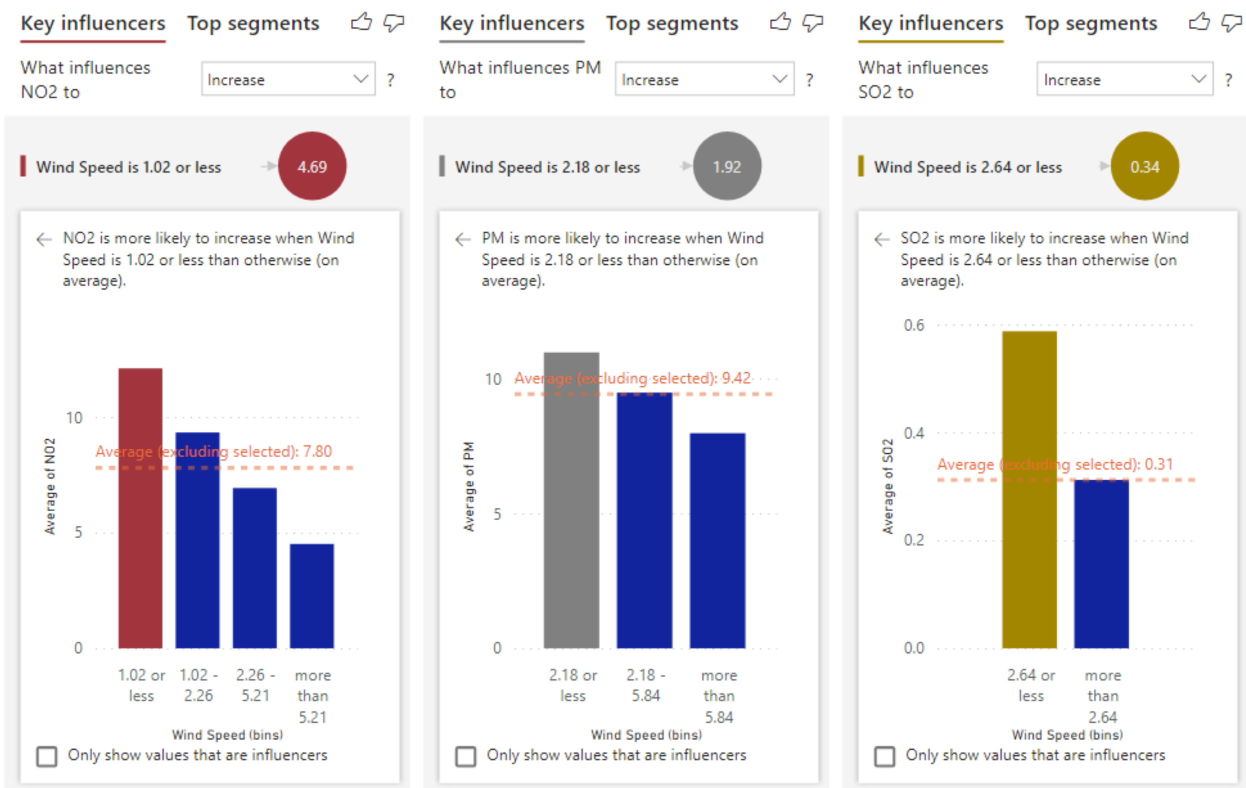


Figure 19. Impacts of Wind Speed on Concentrations

As Figure 19 illustrates, increased wind speed has a significant impact in reducing concentrations. For NO_2 and SO_2, wind speeds higher than 2.2 and 2.6 meters per second, respectively, result in concentration decreases of almost 50 percent.

3.6 Question 8

Are there any significant differences in the data for March 2020 through the COVID pandemic?

3.6.1 Container Volume During COVID

An upward trend in container volume is apparent during the 10+-year monitoring period, as shown on Figure 20.

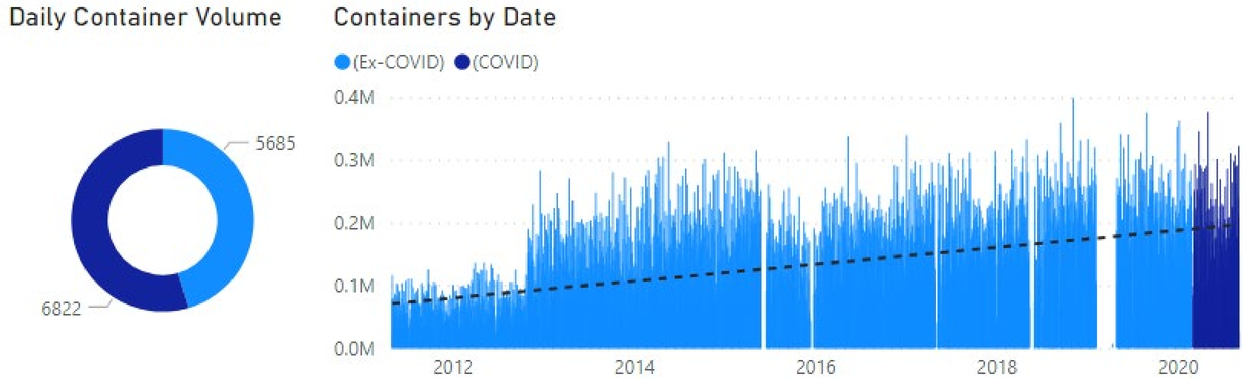


Figure 20. 10-Year Container Volume

However, limiting the analysis to container volume since 2015, a slower increase is identified, as shown on Figure 21. A reduction in volume at the onset of COVID (at least for the first three quarters of 2020) is also observed. Average daily volume during COVID (6,822) is less than the average (7,320) for the previous five years. As noted in Section 2.4, a large increase in the quarter 4 (2020) volume eliminated this deficit.

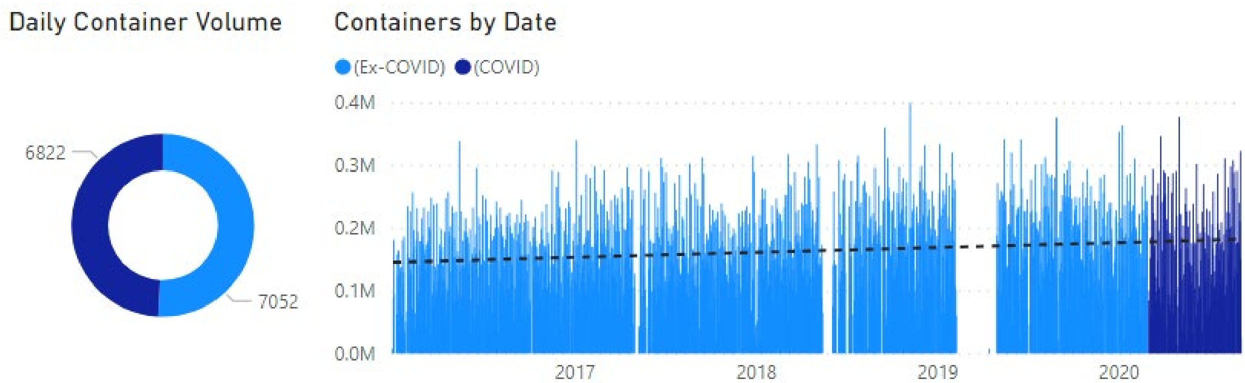


Figure 21. 5-Year Container Volume

3.6.2 Air Quality During COVID

Figure 22 illustrates concentrations of NO_2, $PM_{2.5}$, and SO_2 during COVID (far right) and non-COVID timeframes. NO_2 and SO_2 concentrations show some reduction during COVID, while $PM_{2.5}$ concentrations show limited if any change. The periods in 2020 for which NO_2 and SO_2 data are not shown on the figure (gap in plotted data) are due to the calibration hardware failure near the onset of COVID as discussed in Section 2.4.

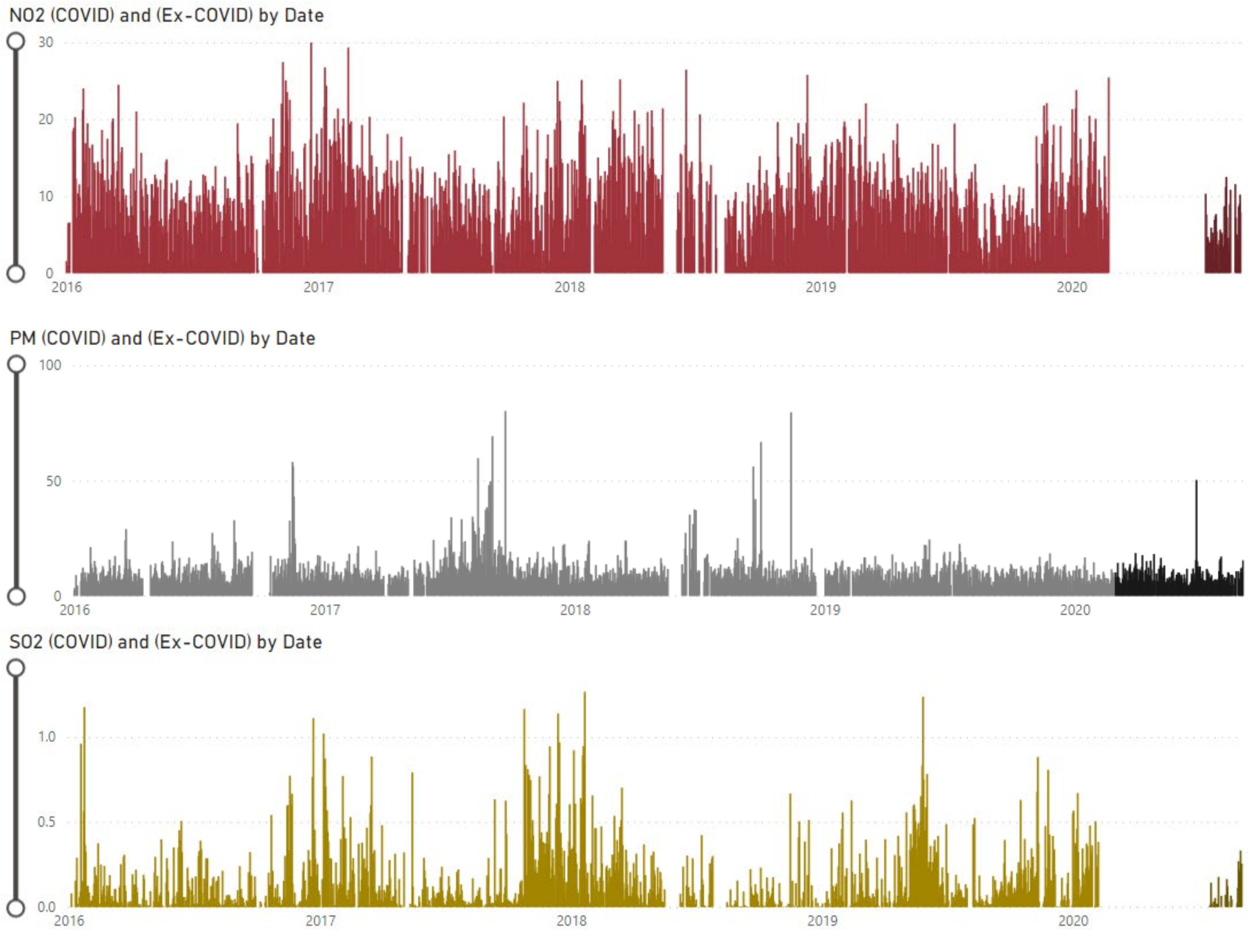


Figure 22. 5-Year Concentrations

4 Analysis Considerations and Data Completeness

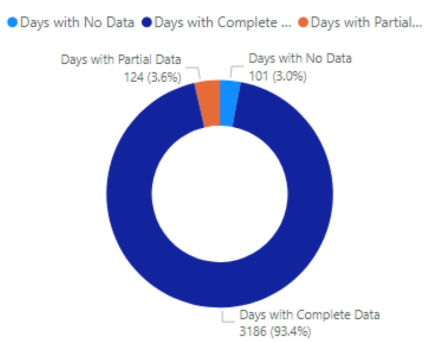
The Power BI analysis included more than nine years of data. As mentioned in Section 1.1, measurements of $PM_{2.5}$, SO_2, and NO_2 were recorded by the monitoring system every 15 seconds, 24 hours per day, 365 days per year during the monitoring program. With limited exceptions resulting from system maintenance, troubleshooting, hardware failure, and calibration, the data completeness throughout the monitoring period was well above 90 percent.

4.1 Timeframe

The period of observation extended from May 4, 2011 through September 3, 2020. Unless otherwise noted below, all 9+ years of the observed data were used in this analysis.

4.2 Data Completeness

The amount of data involved in this study was substantial, representing more than 120 million data observations over the course of almost 10 years. The monitoring equipment was available and producing data during approximately 93.4 percent of the reporting period (3,186 of 3,411 days). Of the approximately 6.6 percent of days with gaps in data, 101 were days where no data were recorded. The remaining 124 days included some partial data collection, but less than for a full 24 hours. Figure 23 summarizes the total and annual breakdown of data collected.



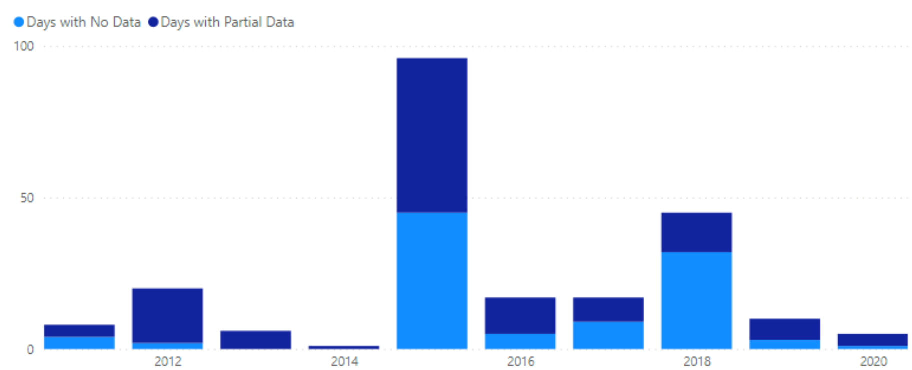


Figure 23. Data Completeness

Data gaps involved a small number of relatively significant events (greater than 2 days) as well as random single-day full or partial outages. Significant outage events include:

- 2015 – This year accounted for 42 percent of the days (96 of 225) where data quality issues occurred, with sporadic outages across multiple parameters and days throughout the year.
- 2018/2019 – There was a period of approximately 6 months (November 2018 to April 2019) where the weather transmitter was out of service. Recording of concentration data was not affected by this outage.
- 2020 – The zero air generator used for daily NO_2 and SO_2 quality checks and instrument calibration failed near the onset of the COVID pandemic. Due to the inability to obtain replacement equipment related to

COVID supply chain interruptions, the outage extended from March through July. The outage did not affect $PM_{2.5}$ or weather monitoring.

4.3 SO_2

After 2015, SO_2 levels at the facility decreased significantly, likely due to federal mandates regarding the use of low sulfur fuel. Since that time, levels have remained near the limits of detectability for the instrument.

4.4 Considerations/Impacts of Low Wind Speed

When evaluating the impacts of wind direction, wind speeds of less than 0.5 meters per second were ignored, consistent with EPA guidance (*Meteorological Monitoring Guidance for Regulatory Modeling Applications, EPA-454/R-99-005, 2000*). Very light winds are often nondirectional.

5 Background and Data Development

The data acquisition system recorded more than 370 million values over the course of the monitoring period. This section discusses the post-processing of this data for input into the Power BI data visualization software. Features of the Power BI software are also discussed as they relate to the analysis of the WWT air monitoring database.

5.1 Existing Data

The system operated from May 4, 2011 through September 3, 2020, producing approximately 3,400 Excel files, one per day. Within each file, 19 individual parameters were recorded at 15-second intervals. The number of recorded data values exceeded 370 million. Data used in this analysis include:

- Wind Data – These data were collected using a Vaisala WXT520 weather transmitter installed on the roof near the inlets of the air quality instruments.
- Concentrations (NO_2, $PM_{2.5}$, and SO_2) – Thermo Fisher's line of air quality instrumentation was used to measure NO_2, $PM_{2.5}$, and SO_2. Thermo Fisher's zero air generator and calibrator were also used to support quality checks and calibration.
- Daily Post-Processing and Quality Checks – During the monitoring period, each daily Excel file was run through a series of macros that calculated hourly averages for NO_2, $PM_{2.5}$, and SO_2 and placed them in a summary table. The macros also generated summary charts within each file. Arcadis staff then performed a quality control check on the summary table.
- Container and Ship Data – SCPA provided Arcadis with two Excel files containing daily container and ship traffic information for 2010 through 2021.

5.2 Data Model Development

The following represents the basic steps performed in developing the data model on which this analysis is based:

- Concentration Data (NO_2, $PM_{2.5}$, and SO_2) – Arcadis developed algorithms to extract the hourly summary tables from each of the approximately 3,400 Excel files and combine them into a series of tables containing the data available for any given year. Those tables were subsequently further combined to produce a single table for the entire reporting period.
- Weather Data – Because no prior work had been done to aggregate the 15-second interval weather data, Arcadis developed algorithms to first calculate hourly averages for five parameters: wind speed, wind direction, temperature, humidity, and barometric pressure. Vector averaging was used in calculating average wind speed and direction. The hourly averages were then combined into a single table for each year. Those tables were further combined to produce a single table for the entire reporting period.
- The concentration, weather, container, and ship data were then combined in a common date table. A series of quality control checks were performed. The results of these checks are discussed in Section 4.2.

5.2.1 Visualization/Dashboard Development

Arcadis' approach to visualization was driven by the key questions presented in the scope of work. Common elements used across the dashboards include:

- Influencer Tool – This tool, available within Power BI, was used to perform the regression analysis. One of many visualization and analytical widgets, this tool enables the user to compare a single 'affected' variable to any number of corresponding 'influencer' variables. The time that the measurements are taken is the common link that enables the regression analysis to be performed.
- Date Filtering – All dashboards have a common date filter that allows the analyst to quickly change the time period being viewed and analyzed. Several key insights to data can be gained through its use (e.g., the changes in SO_2 before and after EPA's low sulfur ruling).
- Wind Filtering – When performing any analysis involving wind direction, a wind filter is applied as appropriate. For this work, such analysis was limited to winds greater than 0.5 meters per second.
- Synchronization – A powerful feature of the platform is that dashboard elements are synchronized throughout. As an example, should the user change the date filter slider (e.g., from 2011-2020 to 2016-2020), other dashboard elements would automatically refresh to reflect that change (e.g., the influencer tool would rerun the regression analysis based on the new dates selected).

Four Power BI files were developed to organize and present the analysis. Each file contains multiple dashboards. Generally, a summary dashboard is included along with more detailed pages for NO_2, $PM_{2.5}$, SO_2, NO, and NO_X. The four files organized the analysis by:

- Time of Day/Week/Holiday
- Weather
- Port Traffic
- COVID

Many of the figures in this report are the direct output of these files.

5.2.2 Tools

Excel – During the course of the monitoring period, Excel was used to process data from the weather transmitter and analyzers. Visual Basic macros were used to calculate hourly NO_2, $PM_{2.5}$, and SO_2 averages and to automatically remove data that were collected during instrument quality checks or calibration periods.

Power BI – Power BI was used to merge, transform, analyze, and present the data.

6 Summary

Following are key findings of the data analysis described in this report:

- NO_2, $PM_{2.5}$, and SO_2 concentrations measured by the monitoring station were in compliance with their respective primary and secondary NAAQS criteria throughout the entire duration of the monitoring period at WWT.
- Time of day was found to be the most impactful influencer of NO_2, $PM_{2.5}$, and SO_2 concentrations. NO_2 and SO_2 were the most impacted by time of day, with the greatest general increases in concentration occurring during normal working hours.
- NO_2 and SO_2 were found to increase in concentration when the wind direction was from the northwest and west of the monitoring station. $PM_{2.5}$ concentrations were generally less impacted by wind direction.
- With respect to wind direction, the greatest increases in concentrations were observed when the wind was from the west and southwest of WWT during working hours. Downtown Charleston is located southwest of WWT, indicating possible contributions from the general community to these concentration increases.
- Concentrations of NO_2, $PM_{2.5}$, and SO_2 were generally found to decrease with increasing wind speed.
- Non-holidays were generally more impactful to NO_2 and $PM_{2.5}$ concentrations, with a notable exception being a detectable increase in $PM_{2.5}$ concentrations on Independence Day. This impact to $PM_{2.5}$ is possibly associated with firework activity from the general community on Independence Day.
- Minimal to no changes in air quality were noted as a result of the COVID pandemic, with NO_2 and SO_2 showing slight decreases in concentration and $PM_{2.5}$ remaining largely unaffected.

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