Impacts of PSEG Nuclear Unit Shutdowns on New Jersey's Ozone Attainment Goals

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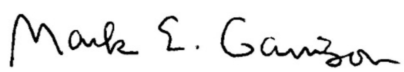

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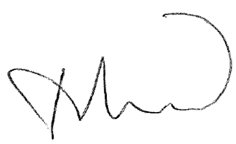

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1. EXECUTIVE SUMMARY

In May 2018, New Jersey Governor Murphy signed legislation directing the New Jersey Board of Public Utilities (BPU) to establish a Zero Emission Certificate (ZEC) program for nuclear power plants that provide electricity to customers in New Jersey. Plants seeking to participate in the ZEC program are required, among other things, to demonstrate that they make a significant contribution to New Jersey air quality and are at risk of closure within three years.

PSEG Nuclear LLC (PSEG Nuclear) owns and operates three of these nuclear units, Hope Creek, Salem 1, and Salem 2, that are eligible to receive ZECs, subject to rulemaking and review and approval by the BPU. These units are located at the Hope Creek-Salem facility in Lower Alloways Creek Township, Salem County, New Jersey. Together, the three units have a rated output of 3,631 megawatts (MW), and supply over one-third of New Jersey's electric power, with essentially zero emissions of oxides of nitrogen (NOx). The loss of the Hope Creek and/or Salem units would result in a shift of electric generation to other units, most of which are higher NOx-emitting fossil fuel fired power plants. This generation shift is projected to increase NOx emissions, both from sources within New Jersey as well as out of state sources.

New Jersey has a long history of being a leader in controlling ozone precursor emissions, including NOx and volatile organic compounds (VOCs), that has resulted in improvements in ozone concentrations across the State and in adjacent states that are part of the interstate air quality control regions (AQCRs) that include New Jersey. Descriptions of some of these measures, that in many cases are more stringent than those implemented in adjacent states, can be found later in this document, and complete descriptions can be found in the State Implementation Plan (SIP) submitted by New Jersey in December 2017[1]. According to this document, control measures implemented in New Jersey have resulted in a decrease in 8-hour ozone concentrations of approximately 39% from 1988 to 2016. To maintain progress towards ozone attainment in New Jersey and more broadly in the interstate AQCRs, it is important to prevent, to the extent possible, any increases in precursor emissions. An illustration of how important it is to limit precursor emission increases is found in an example documented in New Jersey's SIP. Implementation of the NOx emissions budget provisions of the 2016 Cross-State Air Pollution Rule (CSAPR) were predicted to result in only a 0.3 parts per billion (ppb) decrease in 8-hour ozone concentrations at a Connecticut monitor that has recorded the highest concentrations in the AQCR, as compared to the 2015 National Ambient Air Quality Standard (NAAQS) for 8-hour ozone of 70 ppb. As outlined in this report, certain nuclear unit shutdown scenarios result in predicted maximum 8-hour ozone increases of 0.11 ppb.

An independent analysis and report prepared by PA Consulting Group (PA Consulting) demonstrates that power sector NOx emissions from the Pennsylvania-New Jersey-Maryland Interconnection, Mid-Atlantic Area Council Region (PJM MAAC) would materially increase in the near future if the Hope Creek, Salem 1, and/or Salem 2 nuclear generators were to retire. NOx emissions increases were estimated in the PA Consulting report for a "High Electric Demand Day" (HEDD) and a "typical summer day", as a result of the shutdown of one or all three nuclear generating units. NOx is a regional pollutant and an emission precursor to ozone

[1] The State of New Jersey Department of Environmental Protection, State Implementation Plan (SIP) Revision for the Attainment and Maintenance of the Ozone National Ambient Air Quality Standards. December 2017

formation; therefore, regional NOx emission changes stemming from the retirement of Hope Creek, Salem 1, and/or Salem 2 would also contribute to ozone impacts in New Jersey. The adjacent PJM MAAC states of Pennsylvania (PA), Maryland (MD), and Delaware (DE), and in particular PA, are also projected to significantly increase their NOx emissions due to the loss of Hope Creek, Salem 1, and/or Salem 2. Even if any one of these units were to retire, NOx emissions from fossil fuel fired power plants across the PJM states and New York would increase.

As of June 2018, all of New Jersey, along with adjacent counties in Pennsylvania and New York, is designated nonattainment for the 2015 NAAQS for 8-hour ozone of 70 ppb. The two interstate air quality control regions that include New Jersey are the Philadelphia-Wilmington-Atlantic City, PA-NJ-MD-DE area (Southern New Jersey) and the New York-Northern New Jersey-Long Island, NY-NJ-CT area (Northern New Jersey). Southern New Jersey is designated as marginal nonattainment, with a monitor in Camden (Camden County) showing the highest design value for 2019 (4^{th} high, maximum daily 8-hour concentration, averaged over 3 years) of 73 ppb. The highest design value in this AQCR, 76 ppb, is found at a monitor in Bucks County, PA. Northern New Jersey is designated as moderate nonattainment with a monitor at Leonia (Bergen County) showing the highest design value for 2019 of 75 ppb. The highest design value in this AQCR, 82 ppb, are found at the Sherwood Island State Park monitor in Fairfield County, CT, USCG Lighthouse in Fairfield County, CT and Hammonasset State Park in New Haven County, CT.

New Jersey has implemented stringent controls of ozone precursor emissions, including NOx, to address ozone air quality in the State. Reductions in ambient ozone concentrations across New Jersey demonstrate the effectiveness of these controls. However, many of the factors that influence ozone concentrations are not controllable by measures that can be taken by New Jersey. These factors include, among others, natural background, precursor emissions and imported ozone from sources in other states, imported ozone from other countries, and variability in the weather conditions that promote ozone formation. These factors can contribute a significant percentage of the value of the NAAQS to measured ground-level ozone, by some estimates as much as two-thirds of the NAAQS. This leaves a considerably smaller portion of ambient ozone that New Jersey can target with further stringent emission controls to meet the NAAQS.

In this study, photochemical modeling with the Comprehensive Air Quality Model with Extensions (CAMx) model was conducted to estimate the increases in ozone concentrations in New Jersey due to regional increases in NOx emissions that are anticipated to occur based on the retirement of any or all of the nuclear units at Hope Creek or Salem. The model results are based on an ozone episode in 2011. Modeling platforms based on the 2011 ozone episode have been used by many states and interstate organizations in the northeast U.S. to estimate future ozone concentrations for the purpose of attainment planning. Although the modeled ozone values presented in this study are based on the 2011 ozone episode, they are not specific to a particular year; rather, they represent increases that could occur, based on the projected emissions increases, in any future year.

This study, in short, shows that the loss of any or all the Hope Creek and/or Salem units would result in increases in NOx emissions regionally, and consequent increases in ozone concentration in New Jersey. The emissions and ozone impacts are described in both quantity and geographic extent across New Jersey. NOx emissions for the HEDD, 3 Unit Shutdown scenario resulted in an increase of 26 tons/day (tpd) of NOx, primarily from fossil fuel-fired Electric Generating Units (EGUs). This represents a 12.9% increase over Base Case EGU NOx emissions. This increase resulted in a maximum overall 8-hour ozone increase of 0.11 ppb, and a maximum increase at any New Jersey monitor of 0.07 ppb. The modeled increases in ozone concentration are numerically small relative to the NAAQS; however, as discussed in more detail in the body of this report, these increases will make it more difficult for New Jersey to achieve the 70 ppb 8-hour ozone standard across the State, and to achieve attainment of this standard throughout the two interstate AQCRs.

2. INTRODUCTION

In May 2018, the State of New Jersey enacted the ZEC Act[2], which directs the New Jersey BPU to create a program to determine both the eligibility of nuclear generating resources for ZECs, as well as eligible resources' ranking for selection to receive ZECs. The ZEC program is designed for nuclear power plants that provide electricity to customers in New Jersey.

Plants seeking to participate in the ZEC program are required, among other things, to demonstrate that they make a significant contribution to New Jersey air quality and are at risk of closure within three years. PSEG Nuclear owns and operates three nuclear units in New Jersey, Hope Creek, Salem 1, and Salem 2[3], which are eligible to participate in the ZEC program, subject to rulemaking and review and approval by the BPU. These units are located at the Hope Creek-Salem facility in Lower Alloways Creek Township, Salem County, New Jersey.

Salem 1 and 2 began commercial operation in 1977 and 1981, respectively, and their rated outputs are each 1,170 MW. Hope Creek began commercial operation in 1986, and has a rated output of 1,291 MW.[4] Together, the three units have a rated output of 3,631 MW, and supply over one-third of New Jersey's electric power[5], with essentially zero NOx emissions. The loss of the Hope Creek and/or Salem units would result in a shift of electric generation to other units, essentially all of which are NOx-emitting fossil fuel fired power plants. This generation shift is projected to increase NOx emissions, both from sources within New Jersey as well as out of state sources.

The purpose of this air quality study is to assess the ozone impact from the anticipated power generation shift from nuclear power plants owned by PSEG Nuclear to fossil-fuel based power plants in the Eastern U.S. This assessment involved an air quality modeling analysis for ground level ozone, which is formed due to photochemical reactions involving many compounds, principally NOx and VOCs, which are regulated by the EPA as ozone precursor air pollutants. That is, direct emissions of NOx and VOCs from sources such as power plants photochemically react in the atmosphere to produce ground-level ozone that can cause negative impacts to human health and welfare, as well as to plants and animals. Ozone episodes most frequently occur during the hot summer months when atmospheric conditions are most conducive to promoting the necessary photochemical reactions.

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[2] An Act concerning nuclear energy, and supplementing Title 48 of the Revised Statutes [P.L.2018, c.16 (C.48:3-87.3 to 48:3-87.7)].

[3] PSEG has a 100% ownership stake in Hope Creek, and a 57.41% ownership stake in Salem 1 and Salem 2. PSEG operates all three of these units.

[4] PA Consulting, *The Impact of Nuclear Generation Retirements on Emissions and Fuel Diversity in New Jersey*, (October 2018), 7.

[5] For example, in 2017, the three units constituted about 38% of New Jersey's electric power generation.

2.1 Current Ozone Air Quality in New Jersey and in Interstate AQCRs

As of June 2018, all of New Jersey, along with adjacent counties in Pennsylvania and New York, is designated nonattainment for the 2015 NAAQS for 8-hour ozone of 70 ppb. The State is part of two interstate air quality control regions, namely, the Philadelphia-Wilmington-Atlantic City, PA-NJ-MD-DE area (Southern New Jersey) and the New York-Northern New Jersey-Long Island, NY-NJ-CT area (Northern New Jersey). Southern New Jersey is designated as marginal nonattainment, with a monitor in Camden showing the highest design value for 2019 (4th high, maximum daily 8-hour concentration, averaged over 3 years) of 73 ppb. The highest design value in this AQCR, 76 ppb, is found at a monitor in Bucks County, PA. Northern New Jersey is designated as moderate nonattainment with a monitor at Leonia (Bergen County) showing the highest design value for 2019 of 75 ppb. The highest design value in this AQCR, 82 ppb, are found at the Sherwood Island State Park monitor in Fairfield County, CT, USCG Lighthouse in Fairfield County, CT and Hammonasset State Park in New Haven County, CT.

The marginal nonattainment designation for the interstate area including Southern New Jersey signifies that the largest design value at a monitor representing the area is between 71 and 81 ppb[6]. This designation also signifies that attainment is required to be met within 3 years after the designation (which occurred in June 2018), i.e. by June 2021. The June 2021 attainment determination would be based on the design value representing measurements in 2018, 2019, and 2020. The moderate nonattainment designation for the interstate area including Northern New Jersey signifies that the largest design value at a monitor representing the area is between 81 and 93 ppb. This designation also signifies that attainment is required to be met within 6 years after the designation (which occurred in June 2018), i.e. by June 2024. The June 2024 attainment determination would be based on the design value representing measurements in 2021, 2022, and 2023.

Figure 2-1 displays the geographic distribution of measured ozone 8-hour design values in New Jersey, and includes some of the design values from neighboring states that are part of the interstate areas in Northern and Southern New Jersey. The design values shown in this figure represent the average of the 4th high daily maximum 8-hour concentrations measured from 2017 through 2019. For Southern New Jersey, 2018 is the first year that will be included in the future 2020 design value (measured from 2018 through 2020), which is the design value that must be less than or equal to the 8-hour NAAQS of 70 ppb.

[6] https://www.epa.gov/green-book/ozone-designation-and-classification-information accessed in August 2020.

Figure 2-1. Geographic Distribution: 2019 8-hour Ozone Design Values (ppb)

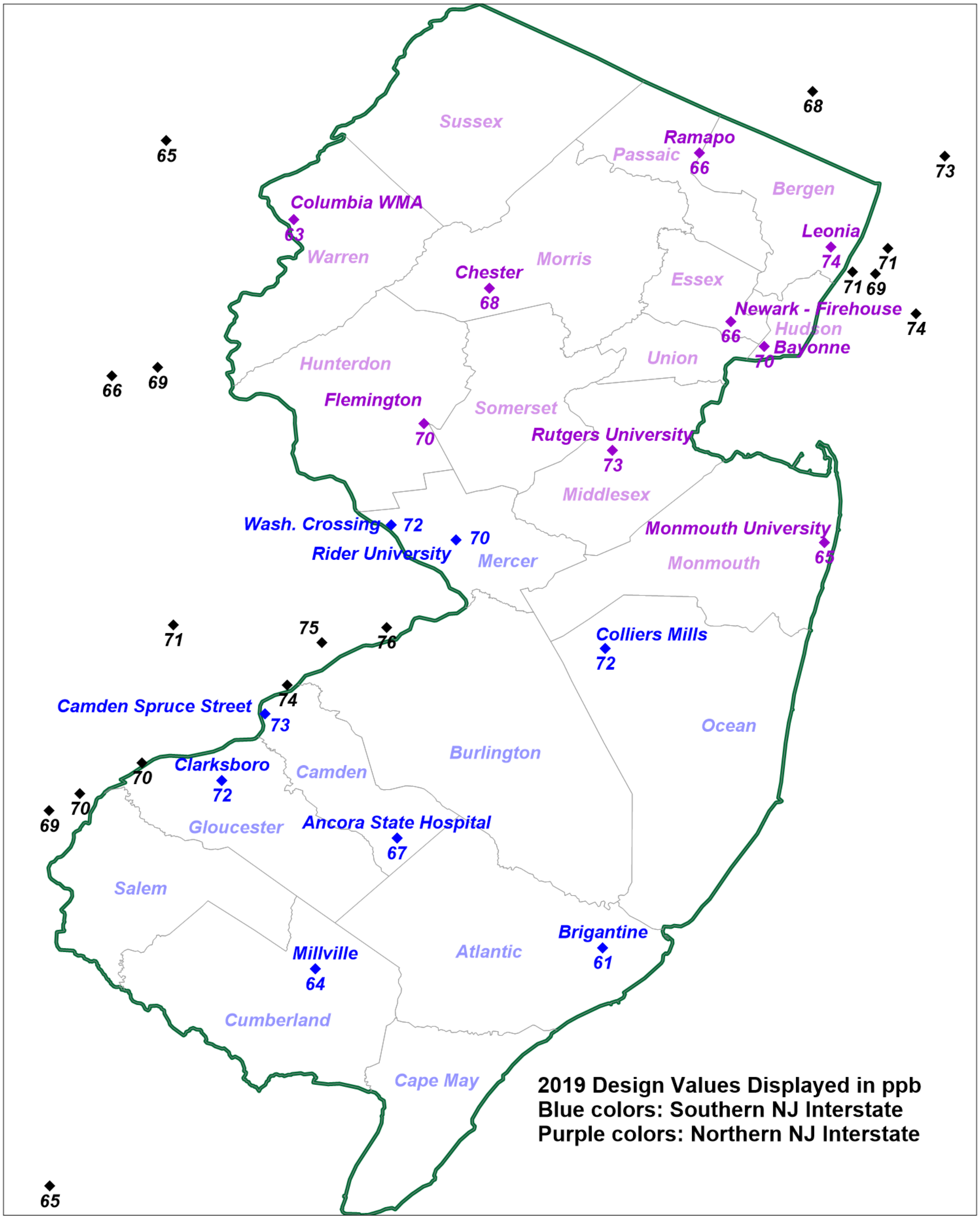


Table 2-1 provides further perspective by listing the 2017-2019 concentrations that make up the 2019 design values. Table 2-1 also shows a derived value labeled "ppb needed for attainment", which is simply the difference between the 2019 design value and the NAAQS. Concentrations in the 3 years of 2018-2020 would have to be reduced (on average) by this value each year in order for the ozone 8-hour NAAQS to be attained by 2021. 2019 design values for all ozone monitors in both AQCRs are presented in the Appendix, Tables A-1 and A-2.

Table 2-1 Summary of 2019 Design Value Composition – 8 hour Ozone

4th High 2017	4th High 2018	4th High 2019	Design Value 2017-2019	N or S Interstate	ppb Reduction Needed for Attainment	County	Name
63	63	59	61	S	-	Atlantic	Brigantine
76	75	70	73	S	3	Camden	Camden Spruce Street
68	68	67	67	S	-	Camden	Ancora State Hospital
63	63	68	64	S	-	Cumberland	Millville
73	77	68	72	S	2	Gloucester	Clarksboro
69	76	66	70	S	0	Mercer	Rider University
71	77	68	72	S	2	Mercer	Wash. Crossing
74	74	68	72	S	2	Ocean	Colliers Mills
74	79	71	74	N	4	Bergen	Leonia
64	71	65	66	N	-	Essex	Newark - Firehouse
67	78	65	70	N	0	Hudson	Bayonne
72	72	66	70	N	0	Hunterdon	Flemington
75	76	70	73	N	3	Middlesex	Rutgers University
60	68	67	65	N	-	Monmouth	Monmouth University
70	73	62	68	N	-	Morris	Chester
66	69	64	66	N	-	Passaic	Ramapo
64	67	58	63	N	-	Warren	Columbia WMA

Finally, Figures 2-2a and 2-2b display the difference in 2018 and 2019 design values at monitors in Southern and Northern New Jersey, respectively. These figures also display the 8-hour ozone NAAQS that have been promulgated over the years, showing the progressive tightening of these standards that makes them increasingly difficult to attain.

Figure 2-2a. 2017-2019 8-hour Ozone Design Values (ppb) for Southern New Jersey

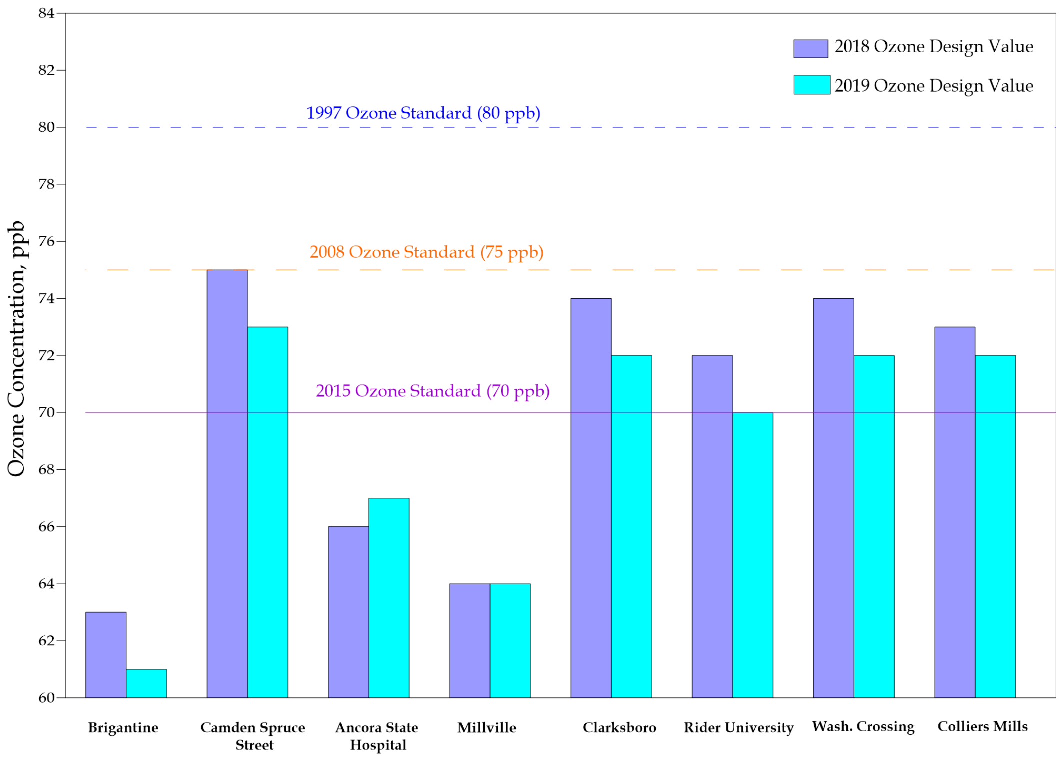
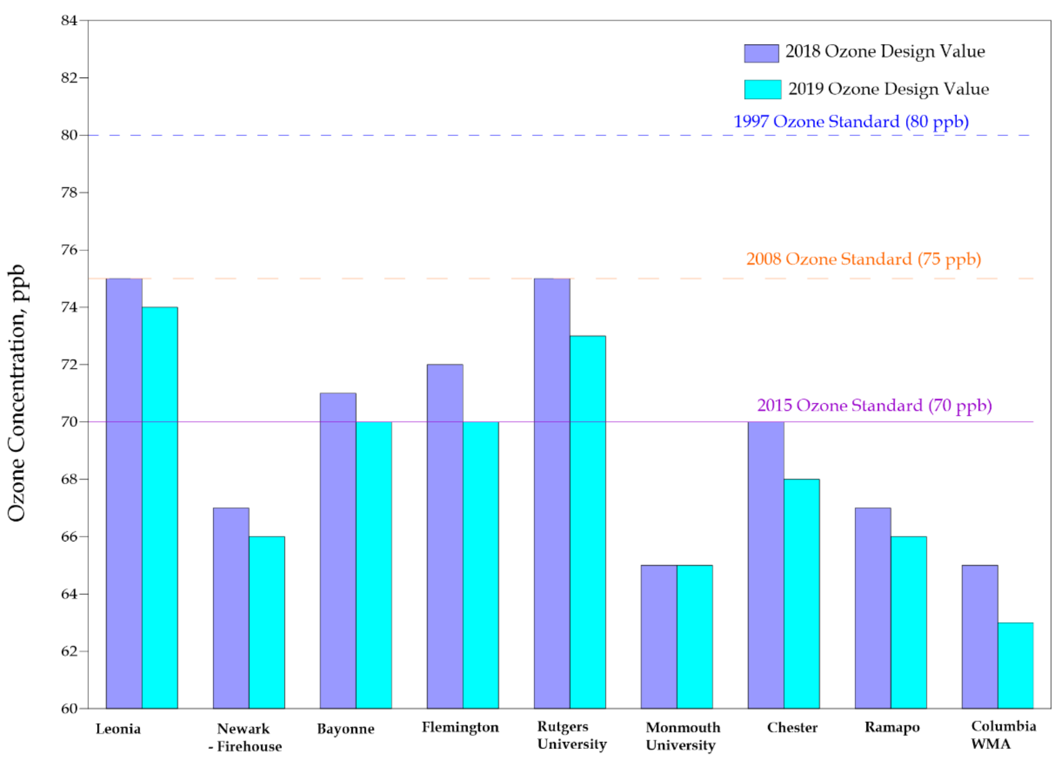


Figure 2-2b. 2017-2019 8-hour Ozone Design Values (ppb) for Northern New Jersey



The purpose of these illustrations is to emphasize that the concentration decreases needed to attain the 8-hour NAAQS in New Jersey are small compared to the value of the NAAQS. The extent of ozone reductions that will be forthcoming due to factors beyond New Jersey's control is unknown at this time. What can be said is that additional reductions in ozone due to the contributions from New Jersey's anthropogenic precursor emissions will likely be needed to attain the NAAQS. New Jersey has already imposed some of the most stringent NOx emission controls in the region on its anthropogenic sources, including controls for power plants, stationary reciprocating internal combustion engines (RICE), municipal waste combustors, and mobile sources. In short, despite imposing some of the most stringent NOx reductions in the nation, New Jersey continues to exceed healthy levels of air pollution for ozone in some locations. Losing any more nuclear generation in New Jersey puts clean air further out of reach.

Power plants in New Jersey are required to limit emissions on a daily basis. Power plants in other states, under Federal rules, are allowed to "trade" high emissions for credits purchased elsewhere, and are also allowed to average emissions across an ozone season. This can lead to higher emissions during HEDD periods, which are frequently associated with high ozone levels. New Jersey, in its SIP submittal, maintains its State-wide restrictions in power plant emissions are among the most stringent of restrictions in adjoining states, and should be extended to other jurisdictions in order to make progress towards ozone attainment. Additionally, because mobile sources are a significant contributor to NOx emissions, New Jersey has implemented voluntary measures (beyond what is required by the Federal government) to control emissions from both on-road and non-road mobile sources. These measures, as described in the SIP submittal, include: reducing the allowable smoke from heavy-duty diesel vehicles during inspection; adding on-board diagnostic (OBD) inspection and maintenance requirements for heavy duty vehicles; adoption of a Low Emission Vehicle (LEV) program, and many others. Due to these and other measures to reduce in-state VOC emissions, New Jersey ozone design values have decreased significantly ranging from two to 10 ppb in the monitors located in the northern New Jersey nonattainment area and two to 12 ppb in the monitors in the southern New Jersey nonattainment area from 2011 to 2016. Through these air emission reduction measures, New Jersey has done its share to address ozone nonattainment, and can ill afford future increases in NOx emissions within the state, as well as out of state increases that result in precursor emissions and ozone transport into the state.

Additional controls will be hard for New Jersey to impose and, given this difficulty, achieving even the relatively small reductions in ozone concentrations needed for attainment will be made even more challenging by factors that increase precursor emissions, such as the loss of nuclear units. The NOx emissions increases projected by the PA Consulting study result from a permanent replacement of the electricity generation provided by the nuclear units at Hope Creek and Salem. Any increase in emissions, and the resulting increase in ozone concentrations discussed in the next section, will make attaining the ozone NAAQS in New Jersey all the more difficult.

The illustrations in Figures 2-2a and 2-2b also show the struggle to maintain ozone levels below the 2008 ozone NAAQS of 75 ppb. On November 2, 2017 EPA determined that the southern New Jersey nonattainment area met the 2008 ozone NAAQS by the attainment date of July 20, 2016. However, subsequent design values (including the period 2017-2019) have shown that the area's air quality data has no room for any increase in ozone concentration to maintain its attainment status for 2008 ozone NAAQS of 75 ppb – and equally important, no room for any increase in order to achieve the 2015 NAAQS of 70 ppb.

3. MODEL AND MODEL INPUTS

Photochemical air quality models are routinely utilized by state regulatory agencies for regional ozone modeling analyses. These photochemical models are large-scale air quality models that simulate the changes of pollutant concentrations in the atmosphere using algorithms that characterize the physical and chemical processes that occur in the atmosphere. These models are intended to accurately depict the ways in which ozone forms, accumulates, and dissipates by simulating the atmospheric processes that are most critical in generating ozone pollution. These models use emissions data from stationary and mobile sources that emit ozone precursors, and simulate the atmospheric reactions that result in ozone formation.

ERM conducted photochemical modeling analyses for ozone to estimate the impacts of the loss of any or all of the Hope Creek and Salem nuclear units on New Jersey's ability to attain and maintain the 70 ppb 8-hour ozone NAAQS.

3.1 Modeling Domain & Emission Inventory

The photochemical modeling study involves an air quality modeling platform that includes emissions, meteorology, and other inputs for the year 2011. The modeling platform that was used to drive the 2011 base year air quality model simulations is collectively called 2011 NEI V3 platform6.3[7]. The base year 2011 platform was chosen in part because it represents the most recent, complete set of base year emissions information currently available for national-scale air quality modeling. Also, modeling conducted by EPA in support of CSAPR[8] was based on calendar year 2011. In addition, the meteorological conditions during the summer of 2011 were conducive to ozone formation across much of the U.S., particularly the eastern U.S.

Figure 3-1 shows the geographic extent of the modeling domain that was used for the air quality modeling in this study. This is a broad domain that covers the 48 contiguous states. This modeling domain contains 25 vertical layers, with a horizontal grid resolution of 12 kilometers (km).

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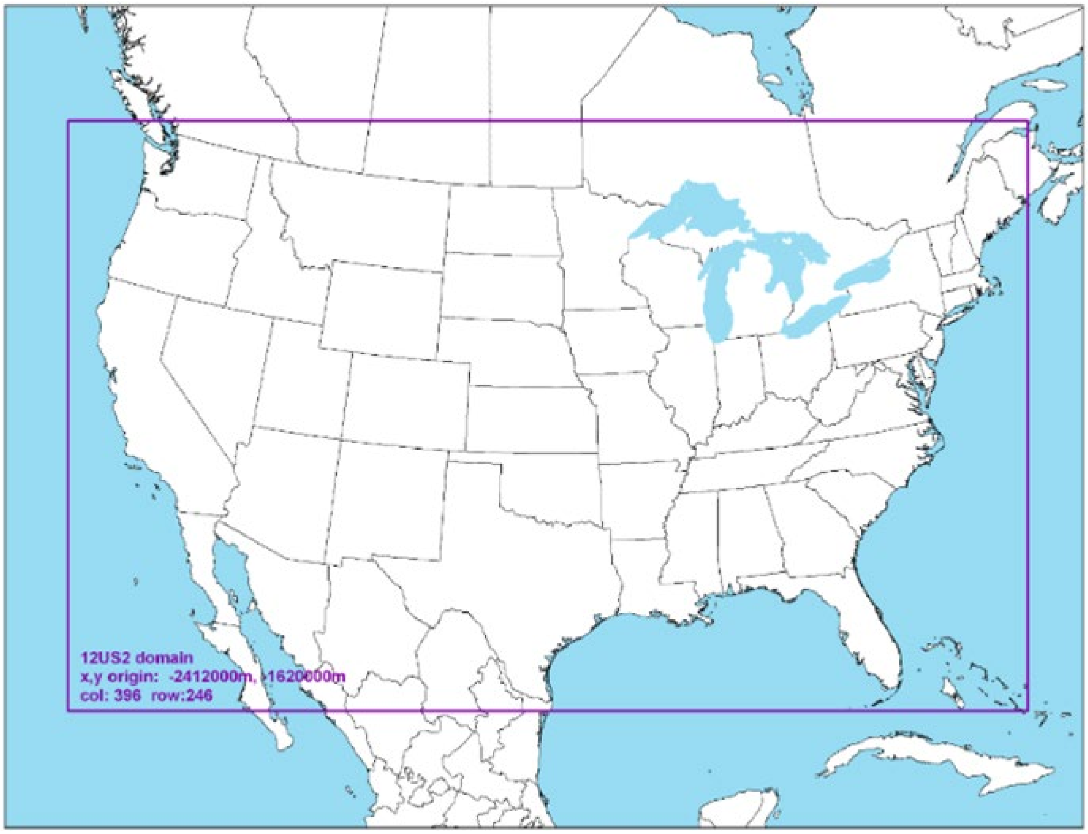
[7] https://www.airqualitymodeling.org/index.php/SMOKE-NEI-Platform6.3 accessed in October 2018.

[8] Interstate Air Pollution Transport, Cross-State Air Pollution Rule Update (2017 - present, updates the CSAPR ozone season NOx program) https://www.epa.gov/airmarkets/final-cross-state-air-pollution-rule-update accessed in October 2018.

Figure 3-1. Modeling Domain



3.2 Identification of Ozone Episodes

ERM utilized the data from PJM to identify the 2011 "HEDD" and "Typical Summer Day" ozone episodes. Based on the "Top 10 All Time Summer/Winter Peak Load Days"[9] as shown in Table 3-1 from PJM, days between July 20-24, 2011 (inclusive) were identified as HEDD, with days between July 14-17, 2011 (inclusive) identified as Typical Summer Days. The ozone modeling was performed for these episodes to assess the increase in ozone formation resulting from various scenarios that represent the shift in power generation resulting from potential nuclear unit shutdowns.

[9] Top 10 All Time Summer/Winter Peak Load Days, PJM, https://www.pjm.com/markets-and-operations/ops-analysis.aspx accessed in October 2018.

Table 3-1. Top 10 All Time Summer/Winter Peak Load Days

Rank	Date	PJM Load MW
1	8/2/2006	144,644
2	**7/21/2011**	**158,043**
3	**7/22/2011**	**151,366**
4	7/18/2013	157,509
5	7/17/2012	154,339
6	**7/20/2011**	**150,060**
7	7/19/2013	156,077
8	7/18/2012	152,758
9	7/17/2013	154,044
10	7/6/2012	151,966

3.3 Emission Processor: SMOKE

Photochemical modeling requires emission inventories containing temporally allocated emissions for each grid-cell in the modeling domain for a large number of chemical species that act as primary pollutants and precursors to secondary pollutants such as ozone. Photochemical modeling also requires emission input files containing hourly emission estimates, distributed both vertically and horizontally in the modeling domain. In order to prepare the 2011 annual emission inventories into photochemical model-ready inputs, the Sparse Matrix Operator Kernel Emissions (SMOKE) [10] modeling system (Houyoux et al., 2000) was utilized. SMOKE is a tool that helps to resolve the annual emissions temporally and spatially, and subsequently prepare the hourly outputs in a format that the photochemical model (i.e. CAMx) can access.

The emission inventory used in this photochemical modeling addressed several source categories, including stationary point sources, area sources, on-road mobile sources, non-road mobile sources, biogenic sources, and fire sources. SMOKE was configured to process the annual emissions from these source categories to develop hourly emissions. With the exception of EGU emissions, pre-computed annual emission from other source categories were temporally allocated to month, day, and hour using annual emissions and Source Classification Code (SCC) based allocation factors. These allocation factors were based on the cross reference and profile data supplied with the SMOKE processor, and were supplemented with relevant data.

To temporally allocate EGU emissions, hourly input from the 2011 Continuous Emissions Monitoring (CEM) [11] dataset were used by SMOKE to develop facility level temporal distributions. For a few EGUs that do not have hourly emissions in the 2011 CEM dataset, SMOKE alternatively uses the annual or day specific emission and facility specific temporal profiles to estimate hourly EGU emissions by facility.

[10] Sparse Matrix Operator Kerner Emissions (SMOKE) Modeling System, https://www.cmascenter.org/smoke/accessed in October 2018.

[11] Air Market Program Data (AMPD). https://ampd.epa.gov/ampd//accessed in October 2018.

3.4 Photochemical Modeling: CAMx

The photochemical model simulations were performed using CAMx [12] version 6.30. CAMx requires a variety of input files that contain information pertaining to the modeling domain and simulation period. These inputs include gridded hourly precursor emissions from SMOKE, meteorological data, and initial and boundary concentrations. The simulations utilized Weather Research and Forecasting (WRF) to develop hourly three dimensional meteorological fields for year 2011. The CAMx simulations were performed using the one-way nesting approach with a 12 km grid spacing. CAMx was applied with the carbon-bond 6 revision 2 (CB6r2) gas-phase chemistry mechanism, and the dry deposition scheme for the full-science study. CAMx modeling was performed to determine changes in 8-hour ozone design values using the "brute force" technique. This consists of performing separate model runs: the first using baseline emissions, and the second including the increased NOx emissions for each scenario. Ozone concentration increases were determined for each grid cell by subtracting the results of the two model runs.

3.5 Modeling Scenarios

PA Consulting was engaged by PSEG to conduct an independent evaluation of projected emissions and fuel diversity impacts due to the retirement of the Hope Creek and Salem nuclear reactors. In this independent evaluation, PA Consulting sought to determine how the retirement of any or all of the Hope Creek, Salem 1, and Salem 2 nuclear generating units would impact electric power generation air pollution and NOx emissions in New Jersey and the surrounding electricity region, as well as how these retirements would impact fuel diversity and grid resilience in New Jersey and the surrounding electricity region.

To this end, PA Consulting conducted a forward-looking analysis over a three year Study Period (January 2022 through December 2025, inclusive) that assessed the emissions and fuel diversity impacts of retiring one or more of these nuclear generating resources. Specifically, PA Consulting modeled the electric system within the U.S. portion of the Eastern Interconnect under the following three cases:

1) "Future Base Case" that represents PA Consulting's independent view of the Eastern Interconnect, including the continued operation of Hope Creek, Salem 1, and Salem 2;
2) "Hope Creek Retirement Case" that assumes Hope Creek does not operate during the Study Period. Due to the similar capacity and electrical location of each of Hope Creek, Salem 1, and Salem 2, this Case serves as a proxy for retiring any single nuclear generating resource. As such, comparing this Case against the Base Case estimates the impacts to electric sector emissions and fuel diversity associated with the retirement of either Hope Creek specifically, Salem 1, or Salem 2;

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[12] Comprehensive Air Quality Model with Extension (CAMx). http://www.camx.com/home.aspx accessed on Oct 2018.

3) "Full Retirement Case" that assumes Hope Creek, Salem 1, and Salem 2 do not operate during the Study Period. The results of the Full Retirement Case are compared to the Base Case to assess the impacts of retiring all three units.[13]

Emission rates and fuel diversity were modeled using a proprietary electricity market modeling process which uses AURORAxmp, an industry standard chronological dispatch simulation model.[14] Additional details on PA Consulting's methods, data, and assumptions, can be found in PA Consulting's report referenced herein.

For this modeling study, ERM relied heavily on PA Consulting's analysis, focused on NOx emissions, and made some adjustments to USEPA's 2011 NEI emission to reflect each particular scenario. The nuclear units are located in close proximity to each other (approximately 300 meters); therefore, ERM believes that one model run is sufficient to characterize the shutdown of any one of the three individual units (two at Salem Creek, one at Hope Creek). ERM, therefore, considered four modeling scenarios: one single unit and one all unit shutdowns, each for the HEDD and Typical Summer Day episodes. In addition to these four future case scenarios, ERM adjusted the EPA's 2011 Base Case emissions to reflect the Future Base Case emissions for year 2022-2025 as projected by PA Consulting. The list of modeling scenarios considered for this air quality assessment is shown in Table 3-2.

Table 3-2. Modeling Scenarios

Scenario #	Scenario	Model ID	Description
1	Base Case HEDD	HEDD_bc	*Model simulation with modified 2011 NEI to reflect the Future Base Case (2020-2022) for HEDD*
2	Base Case Typical	Typi_bc	*Model simulation with modified 2011 NEI to reflect the Future Base Case (2020-2022) for Typical Summer Day*
3	Future Case HEDD 1	HEDD_all	*Model simulation with revised emissions reflecting the shutdown of all three nuclear units for HEDD*
4	Future Case Typical 1	Typi_all	*Model simulation with revised emissions reflecting the shutdown of all three nuclear units for Typical Summer Day*
5	Future Case HEDD 2	HEDD_hope	*Model simulation with revised emissions reflecting the shutdown of one nuclear unit for HEDD*
6	Future Case Typical 2	Typi_hope	*Model simulation with revised emissions reflecting the shutdown of one nuclear unit for Typical Summer Day*

For this modeling analysis, other than the EGU emissions data provided by PA Consulting, all the other anthropogenic emission sources were assumed to operate the same way as in 2011.

[13] PA Consulting, *The Impact of Nuclear Generation Retirements on Emissions and Fuel Diversity in New Jersey*, (August 2020), 8.

[14] Ibid., 15.

3.6 Preparation of Emission Inventories

This section describes the methodology used to develop the emissions inventories that would result from shutdown of any or all of the Hope Creek and/or Salem nuclear reactors. For each modeling scenario listed in the Table 3-2, EGU NOx emissions in 2011 NEI were adjusted based on the daily emissions developed by PA Consulting, which provided daily emissions for both the Future Base Case and future power redistribution scenarios.

For this modeling assessment, ERM has modified the NEI only for EGUs identified by PA consulting. The complete list of NOx emissions in tpd, as provided by PA Consulting, is shown in the Appendix, Table A-3.

In the NEI, EGU emissions are categorized into hourly, daily, and annual emissions based on the availability of emissions in different temporal forms. Most of the EGUs considered in this study use CEM (hourly) data and contribute significantly to total NOx emission in all modeling scenarios. Figures 3-2 through 3-4 show the locations of the EGUs considered in these modeling analyses, along with pictorial representations of the magnitudes of their daily emissions. For emissions available in more than one temporal form, SMOKE preferentially uses the hourly emissions from the CEM database first, followed by daily emissions, and then annual emissions. For sources that do not have hourly emissions or CEM data, SMOKE uses annual emissions and creates hourly inputs using the season and hourly specific factors available for each relevant SCC code in the PJM region.

Figure 3-2. Existing EGUs with CEM data and NOx Base Case Emission (HEDD) over 0.77 tpd

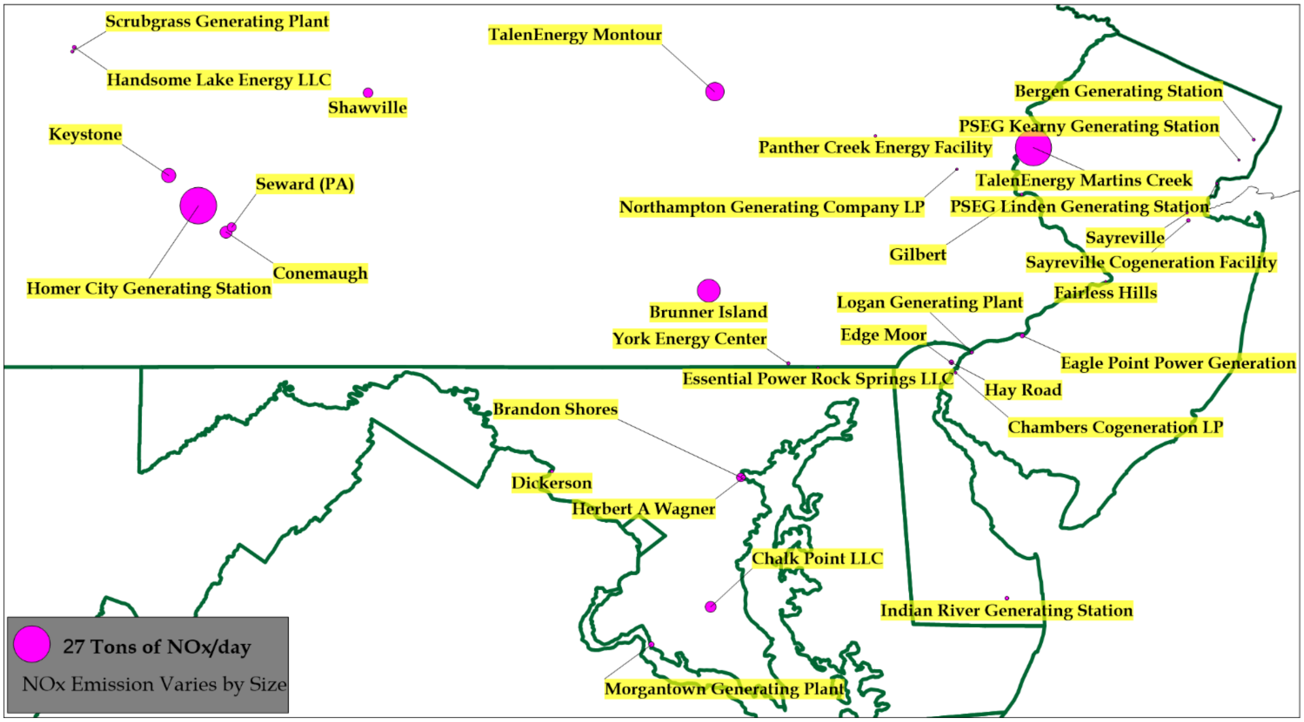


Figure 3-3. Existing EGUs with CEM data and NOx Base Case Emission (HEDD) between 0.77 and 0.3 tpd

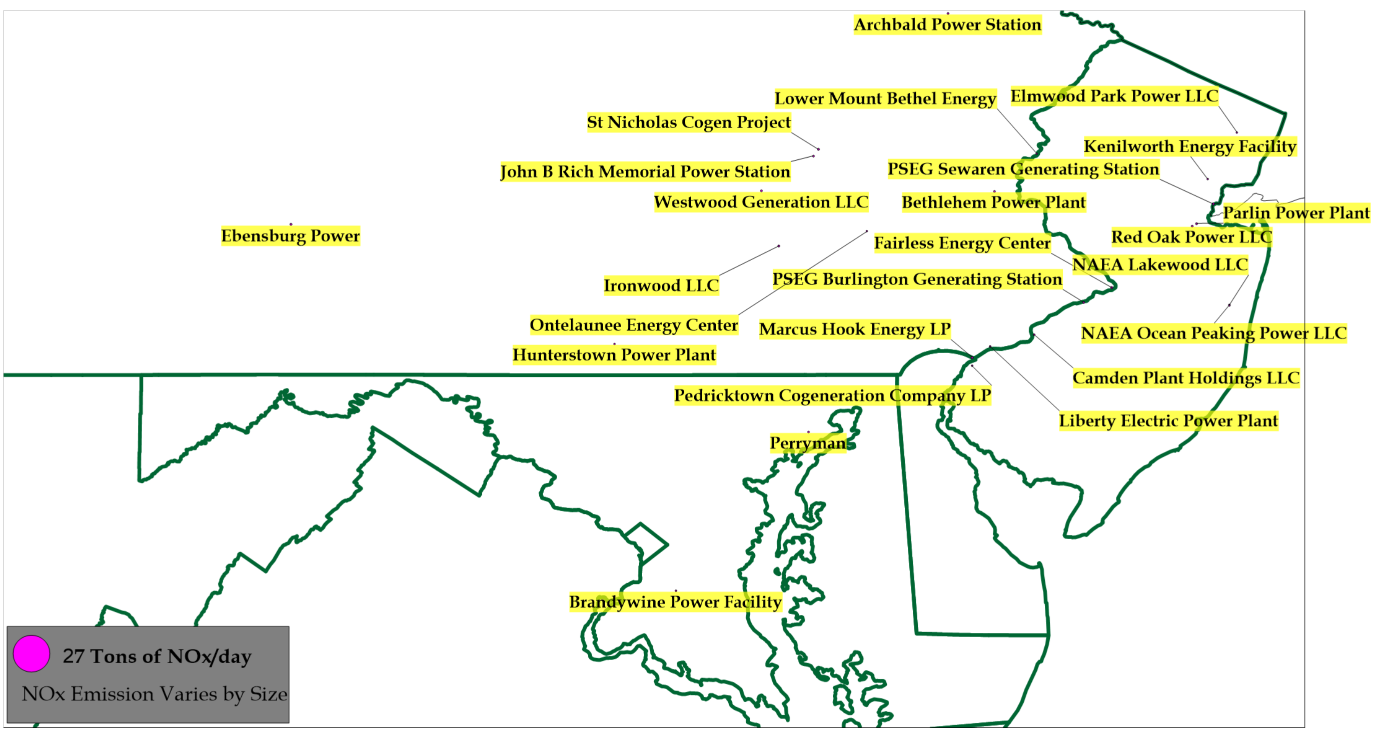
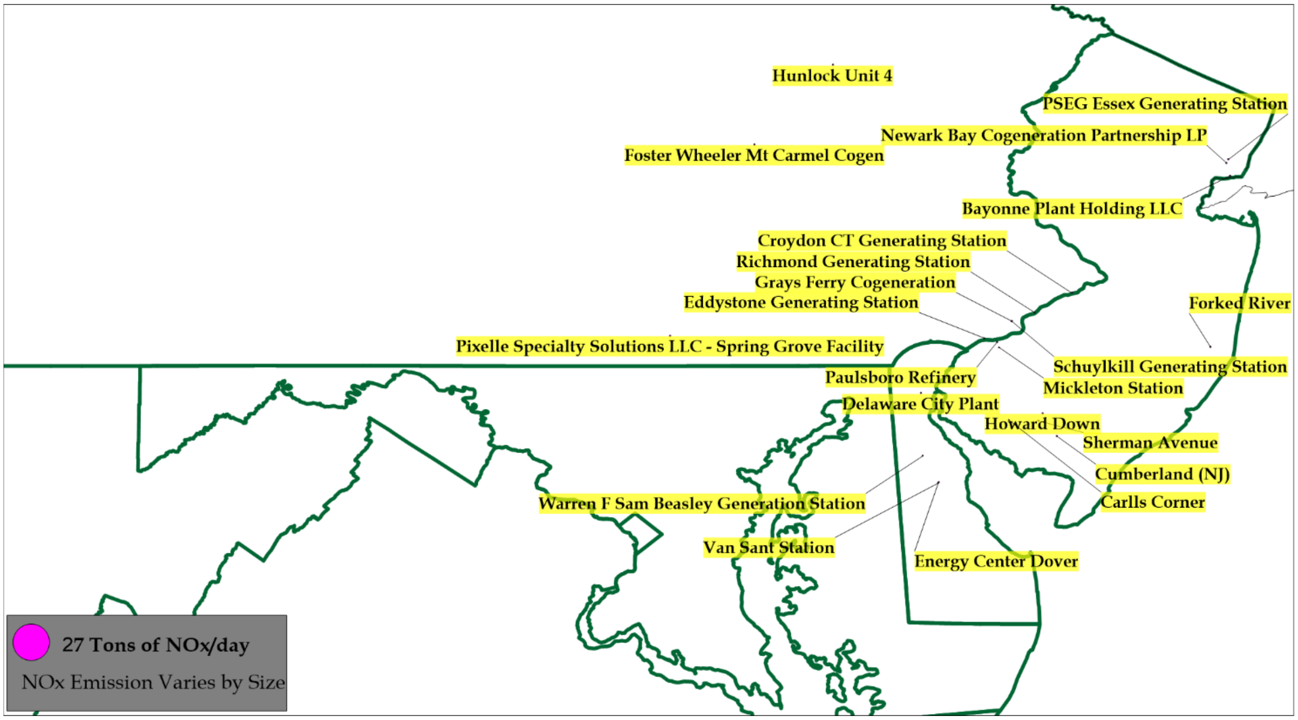


Figure 3-4. Existing EGUs with CEM data and NOx Base Case Emission (HEDD) less than 0.3 tpd

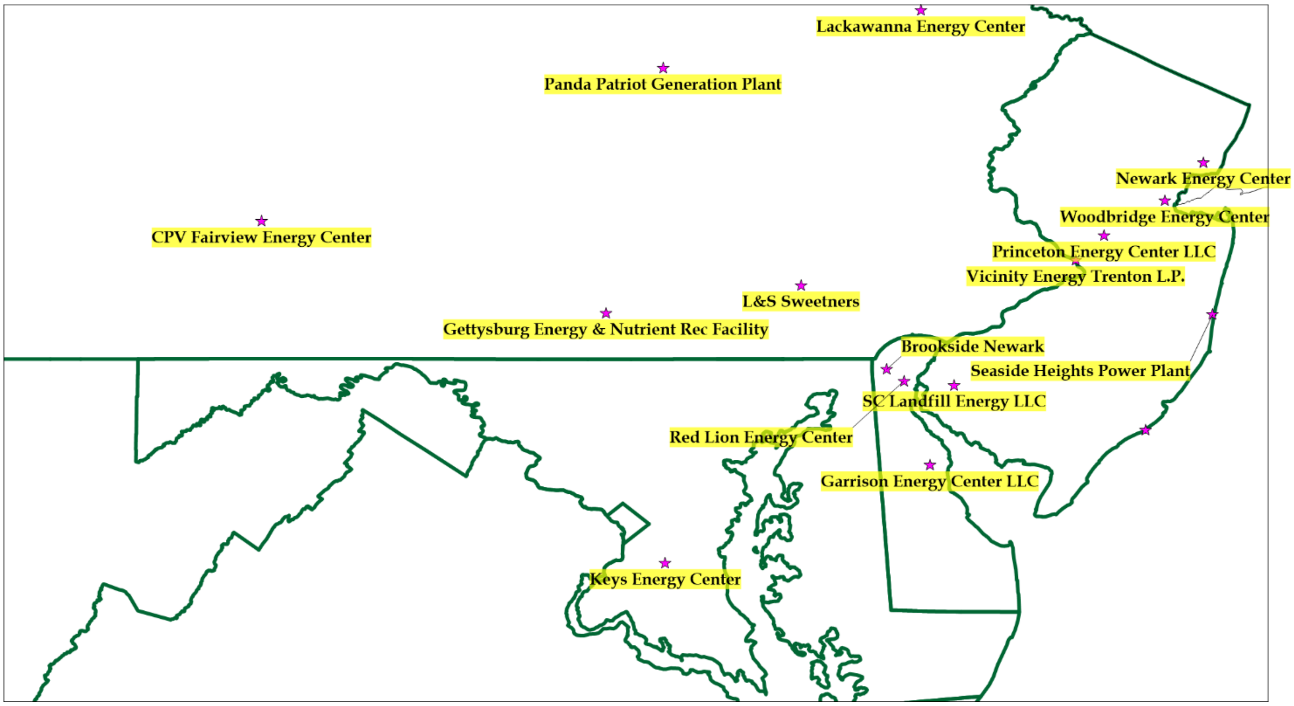


In order to prepare the emission inventory that reflects each scenario, NOx adjustment factors were calculated for each source based on their respective 2011 NEI emissions and the emissions provided by PA Consulting. Once the NOx adjustment factors were calculated, they were applied to the 2011 NOx emissions in all three temporal forms to develop the future scenarios. This process was repeated for each modeling scenario.

For the HEDD scenario, maximum NOx emissions in tpd for each applicable source were determined from 2011 CEM data during the 2011 HEDD episode. These maximum NOx emissions were used in conjunction with HEDD NOx emission data provided by PA Consulting to calculate the NOx adjustment factor for a particular source. Similarly, for the typical scenario, mean NOx emissions in tpd were determined from 2011 CEM data for the month of July, and these values were used in conjunction with typical NOx emissions data provided by PA Consulting to calculate the NOx adjustment factors.

In its analysis, PA Consulting also included new EGUs that have recently begun operating. Figure 3-5 shows the locations of these new EGUs. There are no 2011 NEI emissions available for the new EGU sources to calculate NOx adjustment factors. For these new EGUs, due to lack of hourly or daily emission profile, they could be only represented as annual based emission sources. Therefore, their daily emission values were converted to annual emissions, and the SMOKE emission processor applied the season and hourly specific factors available for specific units in the PJM region. In addition, NOx emissions were removed from the emission inventory for EGUs that have been identified as permanently retired.

Figure 3-5. New EGUs with Annual Emissions



Figures 3-6 through 3-9 display the locations and relative NOx emissions increases for the four scenarios modeled.

Figure 3-6. Increase in NOx Emissions for Future Case HEDD 3-Units Shutdown

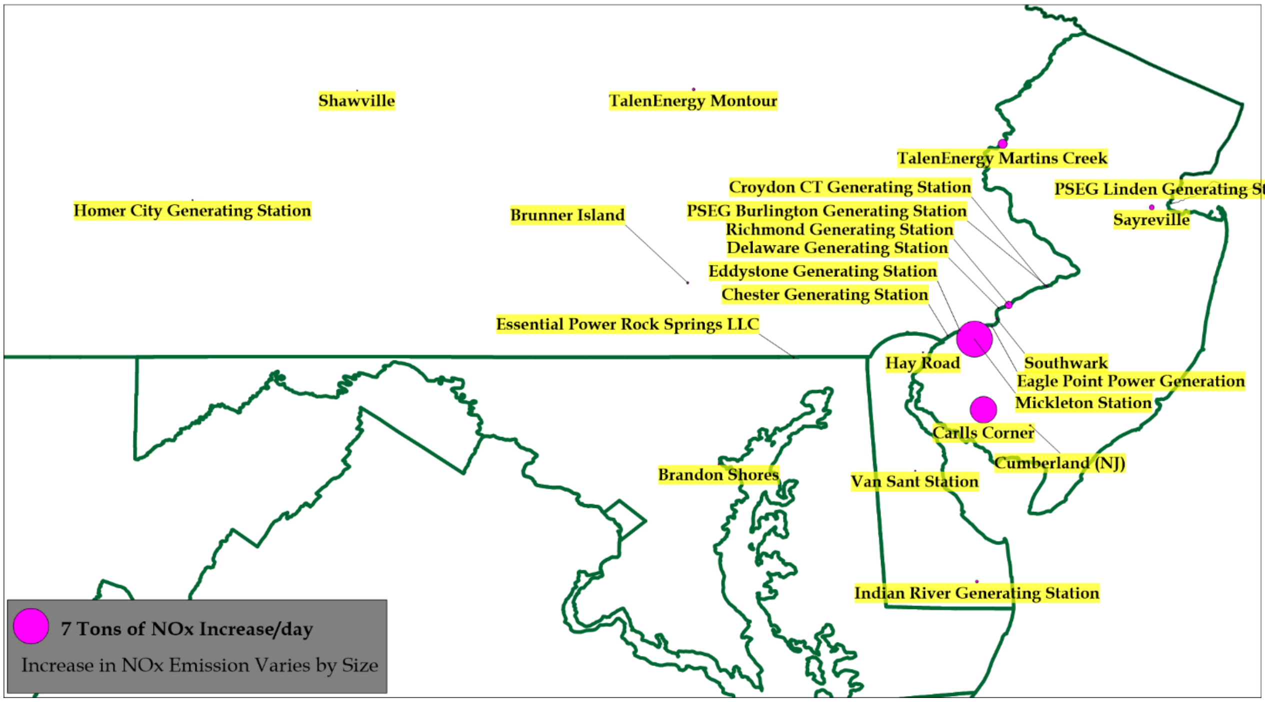


Figure 3-7. Increase in NOx Emissions for Future Case HEDD 1-Unit Shutdown

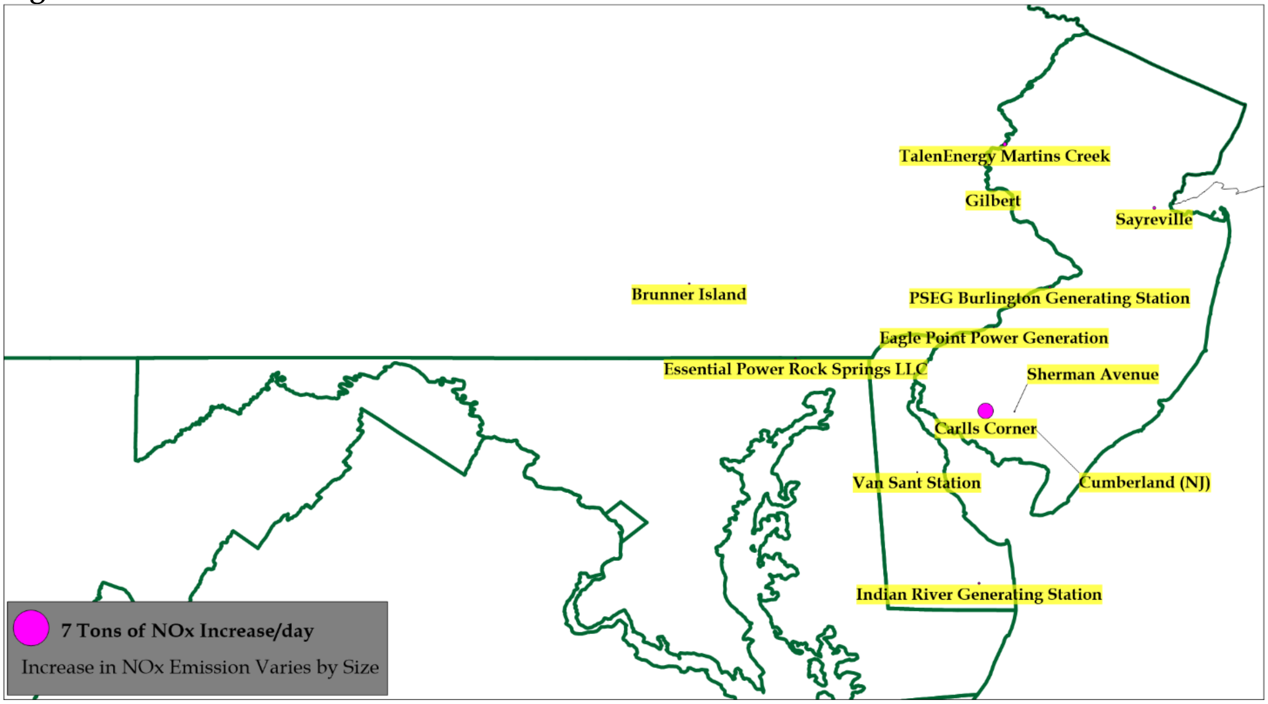


Figure 3-8. Increase in NOx Emissions for Future Case Typical 3-Units Shutdown

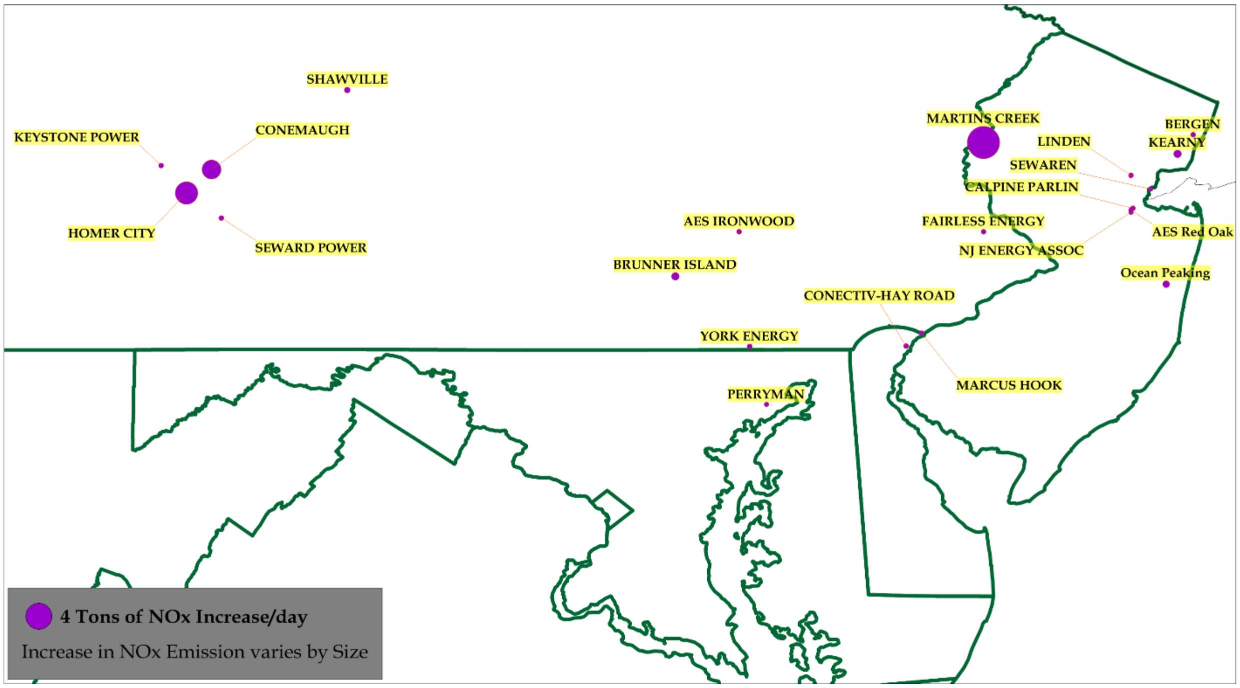
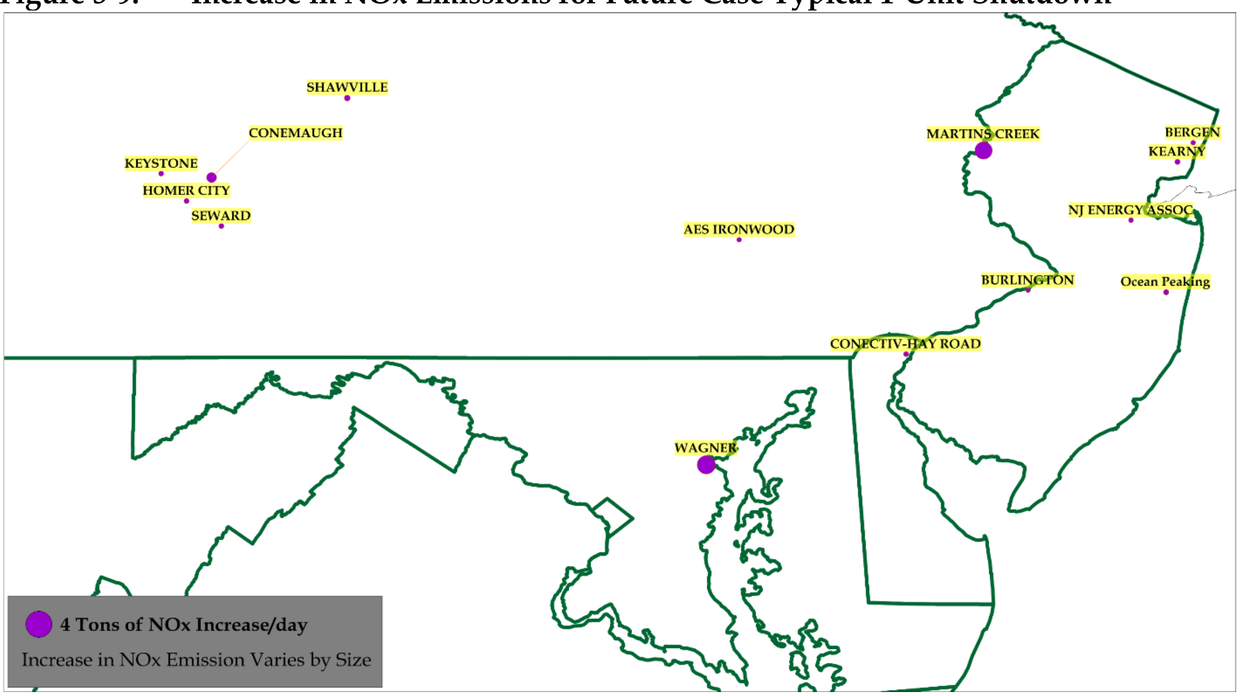


Figure 3-9. Increase in NOx Emissions for Future Case Typical 1-Unit Shutdown



4. RESULTS

Ozone modeling was performed using the photochemical grid model CAMx, following the methodology previously described. This included a "brute force" method in which each of the four scenarios (HEDD or typical, 3-unit or 1-unit shutdown) were run separately from the Base Case. Ozone increases were calculated for each grid cell by subtracting the highest 8-hour concentration for the scenario from the highest 8-hour concentration for the Base Case. The maximum 8-hour ozone increase at New Jersey monitors and the maximum "delta" overall for New Jersey were calculated for each Future Case run. Table 4-1 shows the maximum overall increase in 8-hour ozone concentration for each scenario.

Table 4-1. Maximum Overall Increase in 8-hour Ozone (ppb)

	3 Units Shutdown	1 Unit Shutdown
HEDD	0.109	0.115
Typical	0.065	0.013

Changes in 8-hour ozone concentrations were also calculated for each cell in the modeling domain. Figure 4-1 and 4-2 display contour maps of ozone increases for the HEDD, 3 Units Shutdown scenario and 1 Unit Shutdown scenario respectively, focused on New Jersey.

As illustrated in Figures 4-1 and 4-2, the 3 Units Shutdown scenario has a broader impact than the 1 Unit Shutdown scenario for the HEDD case. Figure 4-1 shows a "hot spot" area located to the southwest of Camden with the maximum predicted ozone increase for the 3 Units shutdown scenario; other areas of smaller increases tend to occur more broadly across Southern New Jersey with less of an influence in the northern part of the state. Figure 4-2, ozone increases due to the 1 Unit Shutdown scenario for the HEDD case, shows a smaller pattern of impact but a slightly higher impact in the same area as Figure 4-1. The marginal decrease in ozone concentration may be due to ozone titration (decreasing concentrations) caused by abundant NOx emissions available during the 3 Units Shutdown scenario. It is important to note that there are uncertainties associated with both the projections of magnitude and location of the NOx increases, and in the modeling of the effect of those increases. Uncertainties in the modeling stem from the fact that these results reflect a single episode associated with an HEDD or typical ozone season time period. It is certain, however, that emissions of NOx will increase as a result of the shutdown of nuclear unit or units at Hope Creek and/or Salem. It is equally certain that these increases will increase ozone concentrations in New Jersey, and add to the difficulties already present related to meeting the 2015 8-hour ozone NAAQS.

Figure 4-1. Geographic Distribution of Maximum Overall Increases in 8-hour Ozone (ppb) for HEDD 3-Units Shutdown Scenario

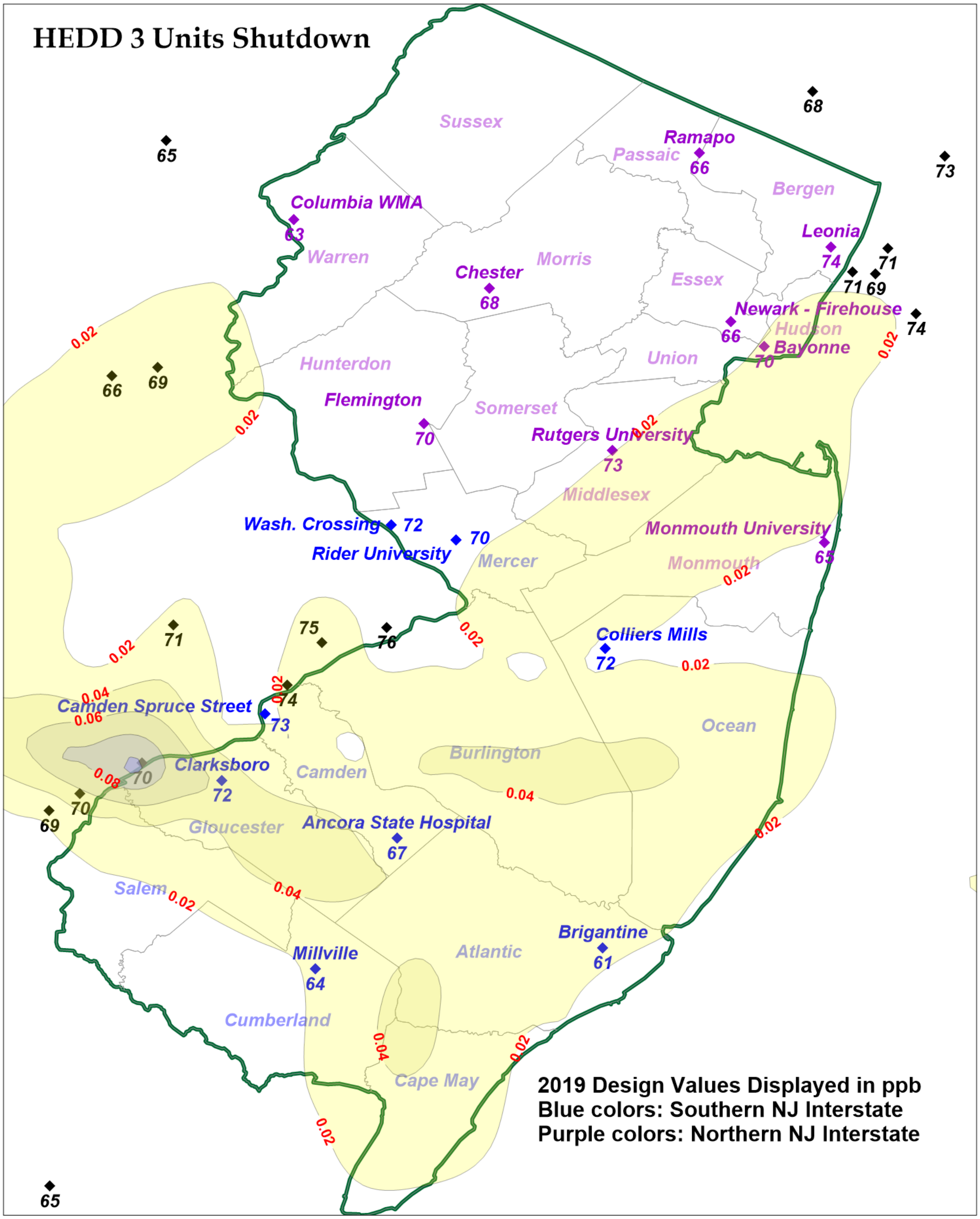
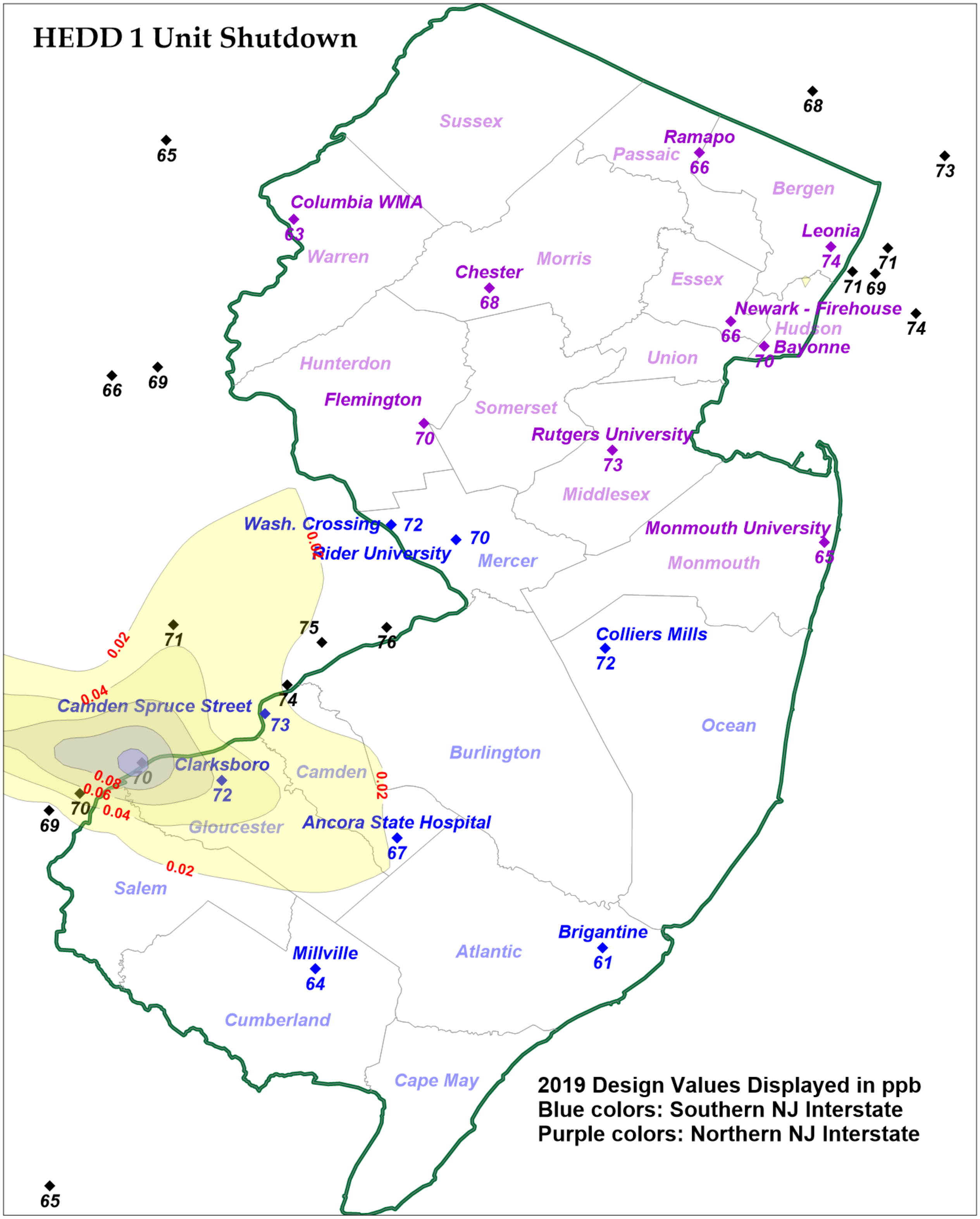


Figure 4-2. Geographic Distribution of Maximum Overall Increases in 8-hour Ozone (ppb) for HEDD 1-Unit Shutdown Scenario



Tables 4-2a and 4-2b, display the maximum 8-hour ozone increase for each monitor location for Southern New Jersey and Northern New Jersey, respectively.

Table 4-2a. Maximum Increase in 8-hour Ozone (ppb) for Each Monitor: Southern New Jersey

Ozone Monitor	HEDD 3 Units Shutdown	HEDD 1 Unit Shutdown	Typical 3 Units Shutdown	Typical 1 Unit Shutdown
Brigantine	0.022	0.003	0.001	0.000
Camden Spruce Street	0.020	0.025	0.003	0.001
Ancora State Hospital	0.021	0.017	0.002	0.001
Millville	0.017	0.008	0.002	0.000
Clarksboro	0.066	0.068	0.003	0.001
Rider University	0.010	0.014	0.003	0.001
Wash. Crossing	0.011	0.016	0.003	0.001
Colliers Mills	0.019	0.005	0.003	0.001

Table 4-2b. Maximum Increase in 8-hour Ozone (ppb) for Each Monitor: Northern New Jersey

Ozone Monitor	HEDD 3 Units Shutdown	HEDD 1 Unit Shutdown	Typical 3 Units Shutdown	Typical 1 Unit Shutdown
Leonia	0.011	0.015	0.007	0.002
Newark - Firehouse	0.007	0.008	0.008	0.002
Bayonne	0.025	0.016	0.005	0.002
Flemington	0.013	0.013	0.005	0.002
Rutgers University	0.020	0.005	0.006	0.002
Monmouth University	0.017	0.005	0.006	0.002
Chester	0.003	0.008	0.009	0.003
Ramapo	0.002	0.003	0.009	0.002
Columbia WMA	0.015	0.002	0.006	0.002

Overall, the increase in 8-hr ozone concertation is higher spatially during the 3 Units Shutdown scenario than during the 1 Unit Shutdown scenario. Interestingly, Tables 4-1, 4-2a and 4-2b show that maximum ozone concentration increases for the 1 Unit Shutdown scenario are marginally greater at some monitors than the concentration increases for the 3 Units Shutdown scenario - a counter-intuitive result. One reason for this might be that for the 1 Unit Shutdown scenario, the location of the NOx increases, even though overall lower than the 3 Units Shutdown scenario, were projected to be geographically closer to some of the monitors, thereby resulting in larger ozone increases. Additionally, a decrease in ozone concentration can be predicted at some grid cells or monitor locations resulting from ozone titration (reduced concentrations) caused by abundant NOx emissions available during the 3 Units Shutdown scenario.

To provide additional perspective on the relationship of changes in NOx emissions and increases in ozone, Figures 4-3 through 4-6 display cumulative NOx emissions from EGUs for the Base Case and the four scenarios considered. The horizontal axis on these figures represents cumulative NOx emissions over all EGUs in the PJM MAAC, for the Base Case and the scenario noted. Specifically:

- Figure 4-3, Scenario 1: HEDD Episode, All Three (3) units shutdown. The increase in NOx emissions across all PJM MAAC EGUs was 26 tpd, a 12.9% increase over Base Case EGU NOx emissions. This caused a maximum increase of 0.109 ppb.
- Figure 4-4, Scenario 2: HEDD Episode, One Unit shutdown. The increase in NOx emissions across all PJM MAAC EGUs was 6.25 tpd, a 3.1% increase over Base Case EGU NOx emissions. This caused a maximum increase of 0.115 ppb.
- Figure 4-5, Scenario 3: Typical Summer Day Episode, All Three (3) Units shutdown. The increase in NOx emissions across all PJM MAAC EGUs was 8.66 tpd, a 5.8% increase over Base Case EGU NOx emissions. This caused a maximum increase of 0.065 ppb.
- Figure 4-6, Scenario 4: Typical Summer Day Episode, One Unit shutdown. The increase in NOx emissions across all PJM MAAC EGUs was 2.44 tpd, a 1.6% increase over Base Case EGU NOx emissions. This caused a maximum increase of 0.013 ppb.

Figure 4-3. Cumulative NOx Emissions leading up to Maximum Increase in 8-hour Ozone for All 3 Units Shutdown (HEDD Episode)

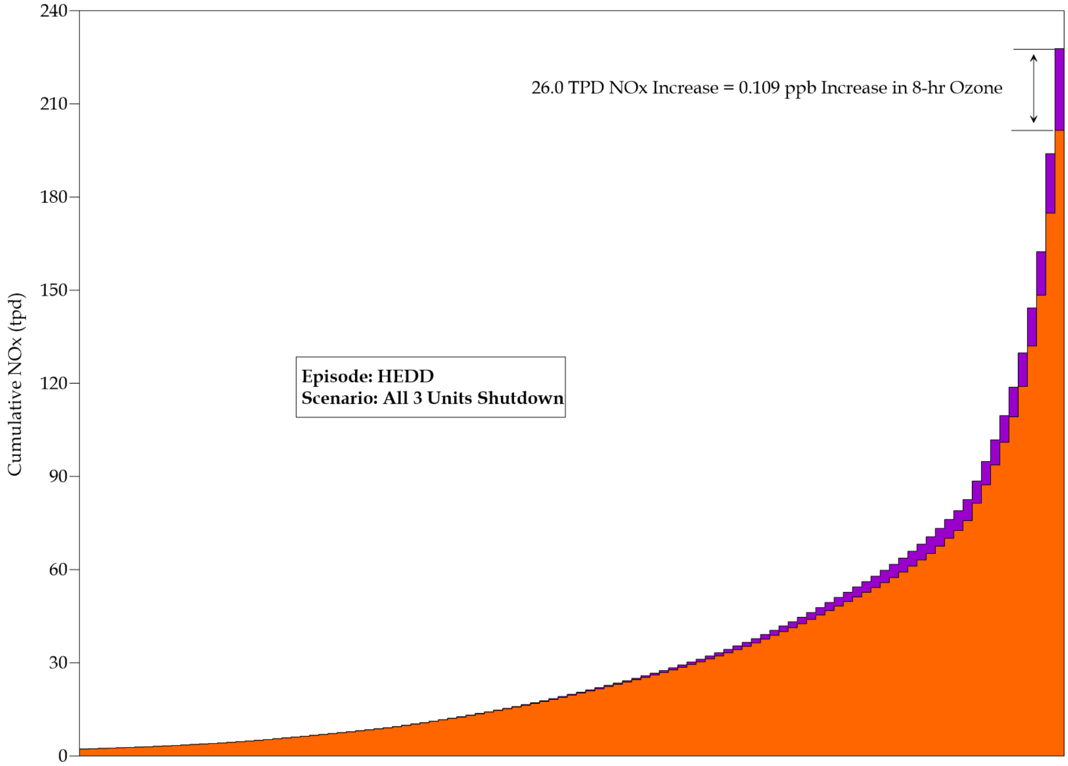


Figure 4-4. Cumulative NOx Emissions leading up to Maximum Increase in 8-hour Ozone for 1 Unit Shutdown (HEDD Episode)

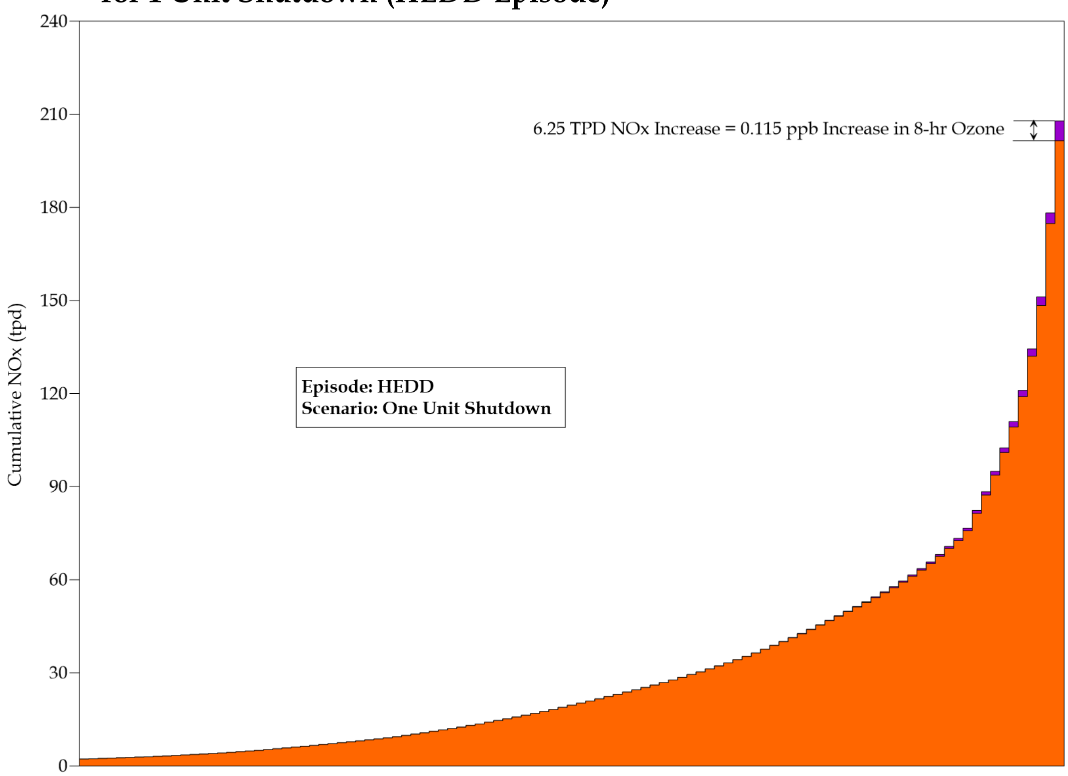


Figure 4-5. Cumulative NOx Emissions leading up to Maximum Increase in 8-hour Ozone for All 3 Units Shutdown (Typical Summer Day Episode)

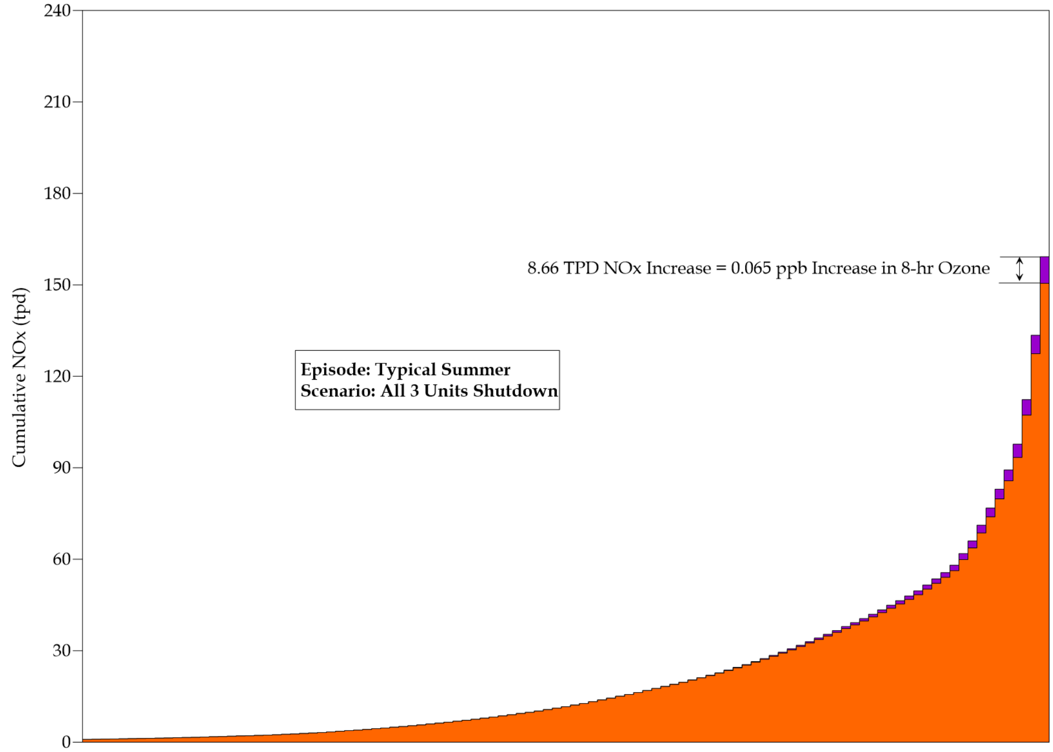
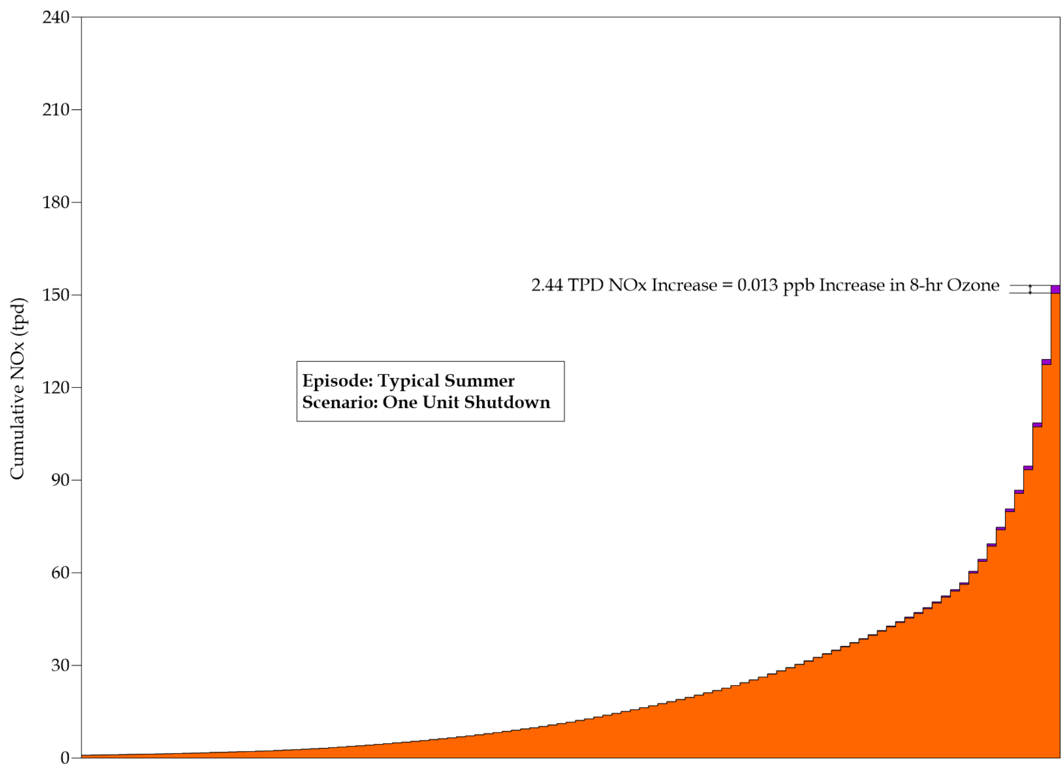


Figure 4-6. Illustration of Cumulative NOx Emissions leading up to Maximum Increase in 8-hour Ozone for 1 Unit Shutdown (Typical Summer Day Episode)



4.1 Changes between 2018 and 2020 PA Consulting Studies

There are some significant changes in NOx emission inputs between the PA Consulting 2018 and 2020 studies, which resulted in a change in the photochemistry simulated by CAMx and consequently had an effect on the overall predicted changes in ozone impacts. Table 4-3 provides a summary of the number of emission sources and NOx emissions (HEDD base and future cases) involved in the two studies. As shown in Table 3-3, the number of emission sources involved in the study increased from 194 to 246. However, the total daily NOx emissions in the base and future cases declined by 34 and 26 tons/day, respectively. Out of 246 EGUs, 54 were shown to have zero NOx emissions in both the base and future cases. The net effect of the overall reduction in total NOx emissions is that the photochemical reactions that are needed to form ozone are less sensitive to further changes in NOx emissions. This effect influences the timing and location of the modeled changes. The overall increase in daily NOx emissions was 18 and 26 tons/day based on the 2018 and 2020 studies, respectively. It would seem intuitive that the larger increase in NOx emissions would result in larger increases in ozone concentrations; however, due in part to the effect described here and as quantified further in previous Sections of this report, the maximum increase in ozone is smaller based on the changes documented in the updated PA Consulting study.

Table 4-3. Comparison of NOx Emissions between 2018 and 2020 Study

Study Year	Number of Sources	Total NOx (tons/day)	
		Base Case Scenario for HEDD	*3 Units Shutdown Scenario for HEDD*
2020	246	201.41	227.47
2018	194	235.49	253.79

5. CONCLUSIONS

An independent analysis and report prepared by PA Consulting Group (PA Consulting) demonstrated that power sector NOx emissions would materially increase in the near future if any or all of the Hope Creek, Salem 1, and Salem 2 nuclear generators were to retire. NOx emissions increases were estimated in the PA Consulting report for a "High Electric Demand Day" (HEDD) and a "typical" summer day, as a result of the shutdown of one or all three nuclear generating units.

In this study, photochemical modeling with the CAMx model was conducted to estimate the increases in ozone concentrations in New Jersey due to regional increases in NOx emissions that are estimated to occur based on the retirement of any or all of the nuclear units at Hope Creek and Salem. The model results are based on an ozone episode in 2011. The 2011 modeling platform has been used by many states and interstate organizations in the northeast U.S. to estimate future ozone concentrations for the purpose of attainment planning. The modeled ozone values presented in this study are not year-specific; rather, they represent increases that could occur, based on the projected emissions increases, in any future year.

This study, in short, shows that the loss of any or all of the Hope Creek and Salem units would result in increases in NOx emissions regionally and consequent increases in ozone concentrations in New Jersey. The emissions and ozone impacts are described in both quantity and geographic extent across New Jersey. NOx emissions for the HEDD, 3 Unit Shutdown scenario resulted in an increase of 26 tpd of NOx from primarily fossil fuel-fired PJM MAAC EGUs (an increase of 12.9% over Base Case PJM MAAC EGU emissions). This resulted in a maximum 8-hour ozone increase of 0.109 ppb, and a maximum increase at any New Jersey monitor of 0.07 ppb. The modeled increases in ozone concentrations are numerically small relative to the NAAQS; however, as discussed in more detail in the body of this report, these increases add to New Jersey's difficulties in achieving the 70 ppb 8-hour ozone NAAQS across the State, especially given the paucity of remaining options in further controlling anthropogenic sources of precursor emissions. New Jersey has done its share to address ozone nonattainment, in New Jersey and throughout the interstate AQCRs, and can ill afford future increases in NOx emissions, within the state as well as out of state, that result in ozone and ozone precursor transport into the state, as New Jersey progresses towards attaining the 8-hour ozone NAAQS of 70 ppb.

6. GLOSSARY

- **AURORA^{xmp}:** Computer-based chronological dispatch simulation model used to project electric generator dispatch and wholesale power prices.
- **BPU:** New Jersey Board of Public Utilities.
- **CAM_x:** Comprehensive Air Quality Model with Extensions.
- **CEM:** Continuous Emissions Monitoring.
- **CO_2:** Carbon dioxide, the primary greenhouse gas emitted through burning fossil fuels (such as coal and natural gas) to generate electricity.
- **CSAPR:** Cross- State Air Pollution Rule.
- **Eastern Interconnect:** A major alternating current electric grid covering much of the eastern US and parts of Canada.
- **EGU:** Electric Generating Unit
- **HEDD:** High Energy Demand Days
- **km:** Kilometer
- **lb:** Pound.
- **LEV:** Low Emission Vehicle, a motor vehicle with relatively low levels of emissions.
- **MAAC Region:** The Mid-Atlantic Area Council Region, a transmission region within PJM that encompasses all or parts of Delaware, DC, Maryland, New Jersey, and Pennsylvania.
- **Metric ton:** a unit of weight equal to 1,000 kilograms (2.20462 pounds).
- **MMBtu:** Million British Thermal Units, a measure of energy content.
- **MSW:** Municipal Solid Waste.
- **MW:** Megawatt.
- **MWh:** Megawatt-hour.
- **MMT:** Million metric tons.
- **$MMTCO_2e$:** Million metric tons of CO_2 equivalent.
- **NAAQS:** National Ambient Air Quality Standards.
- **NEI:** National Emission Inventory.
- **NJDEP:** New Jersey Department of Environmental Protection.
- **NO_x:** Nitrogen oxides, primarily nitric oxide and nitrogen dioxide - air pollutants emitted through burning fossil fuels such as coal and natural gas to generate power.
- **NYISO:** The New York Independent System Operator, a Regional Transmission Organization encompassing the State of New York.
- **OBD:** On Board Diagnostics, a computer-based system built into all gasoline-fueled model year (MY) 1996 and newer light-duty cars and trucks, as well as all diesel-fueled MY 1997 and newer light-duty vehicles**.**

- **PJM:** Pennsylvania-New Jersey-Maryland Interconnection, a Regional Transmission Organization encompassing all or part of 14 Mid-Atlantic, Midwestern, and Southern US states and the District of Columbia.
- **RICE:** Reciprocating Internal Combustion Engine
- **SMOKE:** Sparse Matrix Operator Kernel Emissions.
- **SCC:** Source Classification Code.
- **Study Period:** In this analysis, the three-year period covering June 1, 2019, through May 31, 2022.
- **Ton:** Short ton, equivalent to 2,000 lbs.
- **tpd:** Tons per day
- **USEPA:** US Environmental Protection Agency.
- **VOC:** Volatile Organic Compound.
- **WRF:** Weather Research and Forecasting Model, a next-generation mesoscale numerical weather prediction system designed for both atmospheric research and operational forecasting applications.
- **ZEC:** Zero Emission Certificate or Zero Emission Credit, a policy mechanism enacted in Illinois, New Jersey, and New York to provide financial support for non-energy attributes of nuclear generation.

7. APPENDIX A

Table A-1: 2017 Ozone Design Value for All Monitors in New York-Northern New Jersey-Long Island, NY-NJ-CT AQCR

State Name	County Name	AQS Site ID	2017 4th Highest Daily Max Value	2018 4th Highest Daily Max Value	2019 4th Highest Daily Max Value	2017-2019Design Value
New York-Northern New Jersey-Long Island, NY-NJ-CT						
Connecticut	Fairfield	090010017	74	86	84	81
Connecticut	Fairfield	090011123	72	75	72	73
Connecticut	Fairfield	090013007	81	83	82	82
Connecticut	Fairfield	090019003	81	84	81	82
Connecticut	Middlesex	090070007	79	77	76	77
Connecticut	New Haven	090090027	75	72	78	75
Connecticut	New Haven	090099002	86	77	84	82
New Jersey	Bergen	340030006	74	79	71	74
New Jersey	Essex	340130003	64	71	65	66
New Jersey	Hudson	340170006	67	78	65	70
New Jersey	Hunterdon	340190001	72	72	66	70
New Jersey	Middlesex	340230011	75	76	70	73
New Jersey	Monmouth	340250005	60	68	67	65
New Jersey	Morris	340273001	70	73	62	68
New Jersey	Passaic	340315001	66	69	64	66
New Jersey	Warren	340410007	64	67	58	63
New York	Bronx	360050110	69	71	69	69
New York	Bronx	360050133	69	77	68	71
New York	New York	360610135	70	77	66	71
New York	Queens	360810124	79	73	71	74
New York	Rockland	360870005	66	72	66	68
New York	Suffolk	361030002	77	74	72	74
New York	Suffolk	361030004	76	72	70	72
New York	Suffolk	361030009	71	76	68	71
New York	Westchester	361192004	72	78	69	73

Table A-2: 2017 Ozone Design Value for All Monitors in Philadelphia-Wilmington-Atlantic City, PA-NJ-DE-MD AQCR

State Name	County Name	AQS Site ID	2017 4th Highest Daily Max Value	2018 4th Highest Daily Max Value	2019 4th Highest Daily Max Value	2017-2019Design Value
Philadelphia-Wilmington-Atlantic City, PA-NJ-DE-MD						
Delaware	New Castle	100031007	69	71	64	68
Delaware	New Castle	100031010	74	67	67	69
Delaware	New Castle	100031013	70	72	68	70
Delaware	New Castle	100032004	71	71	67	69
Maryland	Cecil	240150003	75	73	68	72
New Jersey	Atlantic	340010006	63	63	59	61
New Jersey	Camden	340070002	76	75	70	73
New Jersey	Camden	340071001	68	68	67	67
New Jersey	Cumberland	340110007	63	63	68	64
New Jersey	Gloucester	340150002	73	77	68	72
New Jersey	Mercer	340210005	69	76	66	70
New Jersey	Mercer	340219991	71	77	68	72
New Jersey	Ocean	340290006	74	74	68	72
Pennsylvania	Bucks	420170012	79	84	67	76
Pennsylvania	Chester	420290100	71	65	68	68
Pennsylvania	Delaware	420450002	70	73	69	70
Pennsylvania	Montgomery	420910013	76	73	65	71
Pennsylvania	Philadelphia	421010004	42	71	67	60
Pennsylvania	Philadelphia	421010024	76	79	71	75
Pennsylvania	Philadelphia	421010048	76	76	72	74

Table A-3: NOx Emissions in Tons per Day (As provided by PA Consulting)

Note: Emissions other than base case represents the increase in NOx emissions from their respective base case.

	HEDD Episode			Typical Episode		
ORIS	Base case	All Three	Hope Creek	Base case	All Three	Hope Creek
593	0.933	0.000	0.000	0.743	0.000	0.000
594	1.940	0.532	0.306	1.227	0.000	0.000
597	0.000	0.000	0.000	0.000	0.000	0.000
602	5.614	0.272	-0.007	3.649	0.000	0.000
1552	0.000	0.000	0.000	0.000	0.000	0.000
1554	2.511	0.140	-0.042	1.911	-0.056	0.000
1556	0.493	0.046	0.000	0.000	0.011	0.000
1557	0.000	0.000	0.000	0.000	0.000	0.000
1563	0.000	0.000	0.000	0.000	0.000	0.000
1564	0.000	0.000	0.000	0.000	0.000	0.000
1571	7.306	0.133	0.000	3.822	0.000	0.000
1572	1.445	0.124	0.000	0.000	0.000	0.000
1573	3.161	0.000	0.000	2.198	0.045	-0.112
1580	0.000	0.011	0.000	0.000	0.000	0.000
2379	0.000	5.222	2.919	0.000	0.000	0.000
2390	0.865	0.940	0.452	0.000	0.000	0.000
2393	1.262	-0.289	0.099	0.398	0.000	0.000
2398	1.274	0.142	0.034	0.964	0.098	0.034
2399	0.591	0.331	0.254	0.000	0.000	0.000
2401	0.218	0.082	0.027	0.000	0.000	0.000
2404	0.782	0.092	0.037	0.000	0.000	0.000
2406	1.026	0.229	0.067	0.388	0.070	0.015
2410	0.000	0.000	0.000	0.000	0.000	0.000
2411	0.711	0.027	0.006	0.579	0.068	0.029
2434	0.030	0.017	0.017	0.000	0.000	0.000
3109	0.000	0.000	0.000	0.000	0.000	0.000
3110	0.000	0.000	0.000	0.000	0.000	0.000
3111	0.000	0.000	0.000	0.000	0.000	0.000
3112	0.000	0.000	0.000	0.000	0.000	0.000
3113	0.000	0.000	0.000	0.000	0.000	0.000
3114	0.000	0.000	0.000	0.000	0.000	0.000
3115	0.000	0.000	0.000	0.000	0.000	0.000
3116	0.000	0.000	0.000	0.000	0.000	0.000
3118	8.202	0.200	0.000	4.918	0.949	0.088
3120	0.020	0.002	0.000	0.000	0.000	0.000
3122	26.719	0.237	0.000	23.093	0.335	0.015

	HEDD Episode			Typical Episode		
ORIS	Base case	All Three	Hope Creek	Base case	All Three	Hope Creek
3130	5.927	0.000	0.000	5.927	0.000	0.000
3131	6.409	0.210	0.000	5.291	0.300	0.054
3132	0.000	0.000	0.000	0.000	0.000	0.000
3136	9.823	0.000	0.000	7.689	0.199	0.000
3139	0.000	0.000	0.000	0.000	0.000	0.000
3140	16.329	0.412	0.268	13.833	0.779	0.130
3142	0.000	0.000	0.000	0.000	0.000	0.000
3143	0.000	0.000	0.000	0.000	0.000	0.000
3144	0.000	0.000	0.000	0.000	0.000	0.000
3146	0.000	0.000	0.000	0.000	0.000	0.000
3147	0.000	0.000	0.000	0.000	0.000	0.000
3148	26.397	1.783	0.634	20.178	2.662	0.889
3149	13.023	0.503	0.000	5.867	0.000	0.000
3152	0.000	0.000	0.000	0.000	0.000	0.000
3154	0.000	0.000	0.000	0.000	0.000	0.000
3155	0.000	0.000	0.000	0.000	0.000	0.000
3157	0.000	0.279	0.000	0.000	0.000	0.000
3160	0.000	0.283	0.000	0.000	0.000	0.000
3161	0.000	0.367	0.000	0.000	0.000	0.000
3162	0.000	0.000	0.000	0.000	0.000	0.000
3163	0.000	0.088	0.000	0.000	0.000	0.000
3168	0.000	1.431	0.000	0.000	0.000	0.000
3169	0.000	0.193	0.000	0.000	0.000	0.000
3170	0.000	0.372	0.000	0.000	0.000	0.000
3176	0.100	0.004	0.000	0.080	0.011	0.007
3782	0.000	0.000	0.000	0.000	0.000	0.000
3785	0.000	0.000	0.000	0.000	0.000	0.000
4257	0.000	0.076	0.000	0.000	0.000	0.000
5083	0.105	0.286	0.162	0.000	0.000	0.000
6390	0.000	0.000	0.000	0.000	0.000	0.000
6391	0.000	0.001	0.000	0.000	0.000	0.000
6565	0.000	0.000	0.000	0.000	0.000	0.000
6776	0.000	0.000	0.000	0.000	0.000	0.000
7138	0.288	0.186	0.053	0.000	0.000	0.000
7153	2.512	0.258	0.058	1.385	0.779	0.412
7288	0.160	0.170	0.097	0.000	0.000	0.000
7318	0.113	0.227	0.113	0.000	0.000	0.000
7690	0.088	0.000	0.000	0.088	0.000	0.000
7701	0.795	0.000	0.000	0.798	0.000	0.000
7835	0.842	0.284	0.242	0.000	0.000	0.000

	HEDD Episode			Typical Episode		
ORIS	Base case	All Three	Hope Creek	Base case	All Three	Hope Creek
7962	0.085	0.008	0.000	0.000	0.000	0.000
8008	0.000	7.086	0.000	0.000	0.000	0.000
8012	0.000	0.357	0.000	0.000	0.000	0.000
10030	0.054	0.000	0.000	0.043	0.000	0.000
10043	1.493	0.000	0.000	1.233	0.000	0.000
10061	0.003	0.000	0.000	0.002	0.000	0.000
10099	0.316	0.013	0.007	0.249	0.021	0.013
10113	0.541	0.000	0.000	0.606	0.000	0.000
10118	0.213	0.000	0.000	0.214	0.000	0.000
10122	0.000	0.000	0.000	0.000	0.000	0.000
10123	0.000	0.000	0.000	0.000	0.000	0.000
10129	0.000	0.000	0.000	0.000	0.000	0.000
10224	0.000	0.000	0.000	0.000	0.000	0.000
10302	0.013	0.000	0.000	0.013	0.000	0.000
10308	1.724	0.129	0.000	1.143	0.194	0.129
10343	0.280	0.000	0.000	0.315	0.000	0.000
10435	0.740	0.000	0.000	0.754	0.000	0.000
10566	1.233	0.000	0.000	1.246	0.000	0.000
10603	0.698	0.000	0.000	0.650	0.000	0.000
10629	1.138	0.000	0.000	1.137	0.000	0.000
10643	0.870	0.000	0.000	0.887	0.000	0.000
10693	0.000	0.000	0.000	0.000	0.000	0.000
10746	1.441	0.000	0.000	1.447	0.000	0.000
10751	0.441	0.059	0.043	0.356	0.061	0.025
10805	0.363	0.000	0.000	0.316	0.000	0.000
10870	0.000	0.000	0.000	0.000	0.000	0.000
50094	0.000	0.000	0.000	0.000	0.000	0.000
50215	0.519	0.000	0.000	0.521	0.000	0.000
50279	0.560	0.016	0.016	0.383	0.000	0.000
50373	0.001	0.000	0.000	0.001	0.000	0.000
50385	0.217	0.000	0.000	0.231	0.000	0.000
50411	0.000	0.000	0.000	0.000	0.000	0.000
50463	0.000	0.000	0.000	0.000	0.000	0.000
50497	0.275	0.000	0.000	0.240	0.000	0.000
50561	2.371	0.351	0.117	1.954	0.381	0.075
50611	0.617	0.000	0.000	0.617	0.000	0.000
50628	0.236	0.055	0.018	0.000	0.145	0.073
50657	0.862	0.000	0.000	0.861	0.000	0.000
50776	1.222	0.076	0.000	1.108	0.088	0.013
50799	0.683	0.023	0.009	0.517	0.041	0.000

	HEDD Episode			Typical Episode		
ORIS	Base case	All Three	Hope Creek	Base case	All Three	Hope Creek
50852	0.409	0.006	0.006	0.331	0.042	0.012
50859	0.601	0.000	0.000	0.604	0.000	0.000
50885	0.244	0.000	0.000	0.249	0.000	0.000
50888	0.992	0.000	0.000	1.042	0.000	0.000
50960	0.668	0.000	0.000	0.681	0.000	0.000
50974	1.385	0.000	0.000	1.437	0.000	0.000
52149	0.000	0.000	0.000	0.000	0.000	0.000
52193	0.211	0.000	0.000	0.235	0.000	0.000
54250	0.000	0.000	0.000	0.000	0.000	0.000
54333	0.001	0.000	0.000	0.001	0.000	0.000
54569	0.000	0.000	0.000	0.000	0.000	0.000
54625	0.474	0.000	0.000	0.476	0.000	0.000
54634	0.693	0.000	0.000	0.693	0.000	0.000
54640	0.311	0.023	0.002	0.206	0.047	0.023
54693	0.114	0.001	0.001	0.082	0.005	0.009
54708	0.000	0.000	0.000	0.000	0.000	0.000
54746	0.651	0.000	0.000	0.654	0.000	0.000
54785	0.290	0.000	0.000	0.270	0.000	0.000
54795	0.000	0.000	0.000	0.000	0.000	0.000
54829	0.000	0.000	0.000	0.000	0.000	0.000
54832	0.469	0.000	-0.015	0.408	0.000	0.000
54934	0.074	0.000	0.000	0.074	0.000	0.000
54980	0.156	0.000	0.000	0.159	0.000	0.000
55074	0.069	0.000	0.000	0.069	0.000	0.000
55193	0.319	0.009	0.000	0.291	0.009	0.009
55231	0.424	0.007	0.000	0.353	0.051	0.031
55233	1.987	0.000	0.000	0.000	0.000	0.000
55239	0.564	0.017	0.000	0.478	0.052	0.017
55298	0.723	0.009	0.003	0.591	0.102	0.052
55337	0.681	0.000	0.000	0.671	0.011	0.011
55381	0.000	1.244	0.000	0.000	0.000	0.000
55524	1.525	0.047	0.038	1.161	0.298	0.104
55667	0.464	0.007	0.004	0.432	0.022	0.004
55690	0.532	0.016	0.000	0.453	0.055	0.033
55765	0.107	0.000	0.000	0.108	0.000	0.000
55801	0.775	0.046	0.000	0.624	0.076	0.031
55885	0.024	0.000	0.000	0.024	0.000	0.000
55938	0.447	0.103	0.053	0.000	0.000	0.000
55964	0.054	0.000	0.000	0.054	0.000	0.000
55976	0.321	0.000	0.000	0.314	0.000	0.000

	HEDD Episode			Typical Episode		
ORIS	Base case	All Three	Hope Creek	Base case	All Three	Hope Creek
56038	0.000	0.000	0.000	0.000	0.000	0.000
56050	0.000	0.000	0.000	0.000	0.000	0.000
56397	0.168	0.000	0.000	0.000	0.000	0.000
56429	0.053	0.000	0.000	0.051	0.000	0.000
56430	0.056	0.000	0.000	0.054	0.000	0.000
56510	0.018	0.000	0.000	0.018	0.000	0.000
56511	0.023	0.000	0.000	0.023	0.000	0.000
56512	0.035	0.000	0.000	0.035	0.000	0.000
56513	0.000	0.000	0.000	0.000	0.000	0.000
56571	0.039	0.000	0.000	0.039	0.000	0.000
56680	0.052	0.000	0.000	0.051	0.000	0.000
56690	0.062	0.000	0.000	0.062	0.000	0.000
56701	0.004	0.000	0.000	0.003	0.000	0.000
56846	0.975	0.000	0.000	0.889	0.000	0.000
56850	0.043	0.000	0.000	0.043	0.000	0.000
56873	0.024	0.000	0.000	0.025	0.000	0.000
56884	0.053	0.000	0.000	0.054	0.000	0.000
56887	0.071	0.000	0.000	0.071	0.000	0.000
56890	0.018	0.000	0.000	0.018	0.000	0.000
56911	0.161	0.000	0.000	0.162	0.000	0.000
56957	0.086	0.000	0.000	0.086	0.000	0.000
56963	0.280	0.035	0.023	0.200	0.036	0.009
57183	0.033	0.000	0.000	0.033	0.000	0.000
57349	0.144	0.012	0.008	0.107	0.018	0.009
57581	0.033	0.000	0.000	0.033	0.000	0.000
57582	0.034	0.000	0.000	0.034	0.000	0.000
57788	0.031	0.000	0.000	0.031	0.000	0.000
57839	0.284	0.006	0.001	0.202	0.026	0.001
57843	0.020	0.000	0.000	0.020	0.000	0.000
57845	0.056	0.000	0.000	0.057	0.000	0.000
57846	0.035	0.000	0.000	0.036	0.000	0.000
57847	0.089	0.000	0.000	0.091	0.000	0.000
57848	0.024	0.000	0.000	0.025	0.000	0.000
58051	0.000	0.000	0.000	0.000	0.000	0.000
58079	0.272	0.030	0.007	0.190	0.030	0.005
58110	0.000	0.002	0.001	0.000	0.000	0.000
58165	0.013	0.000	0.000	0.012	0.000	0.000
58172	0.000	0.000	0.000	0.000	0.000	0.000
58207	0.069	0.000	0.000	0.050	0.000	0.000
58208	0.101	0.000	0.000	0.103	0.000	0.000

	HEDD Episode			Typical Episode		
ORIS	Base case	All Three	Hope Creek	Base case	All Three	Hope Creek
58235	0.022	0.013	0.007	0.000	0.000	0.000
58246	0.029	0.000	0.000	0.029	0.000	0.000
58250	0.015	0.000	0.000	0.015	0.000	0.000
58252	0.010	0.000	0.000	0.010	0.000	0.000
58326	0.071	0.000	0.000	0.071	0.000	0.000
58420	1.400	0.000	0.000	1.194	0.083	0.037
58426	1.193	0.023	0.000	1.058	0.056	0.000
58433	0.002	0.013	0.007	0.000	0.000	0.000
58442	0.119	0.000	0.000	0.115	0.000	0.000
58476	0.132	0.000	0.000	0.133	0.000	0.000
58497	0.031	0.000	0.000	0.031	0.000	0.000
58584	0.029	0.000	0.000	0.026	0.000	0.000
58714	0.023	0.002	0.000	0.000	0.008	0.000
58715	0.016	0.004	0.000	0.000	0.000	0.000
58811	0.008	0.002	0.001	0.000	0.000	0.000
58813	0.018	0.001	0.001	0.000	0.000	0.000
58818	0.018	0.001	0.001	0.000	0.000	0.000
58821	0.023	0.002	0.000	0.000	0.008	0.000
58897	0.000	0.000	0.000	0.000	0.000	0.000
58947	0.033	0.000	0.000	0.031	0.000	0.000
59012	0.104	0.000	0.000	0.101	0.000	0.000
59026	0.018	0.000	0.000	0.018	0.000	0.000
59055	0.000	0.000	0.000	0.000	0.000	0.000
59056	0.003	0.000	0.000	0.000	0.000	0.000
59073	0.304	0.000	0.000	0.277	0.000	0.000
59116	0.027	0.000	0.000	0.028	0.000	0.000
59220	1.441	0.069	0.014	0.947	0.270	0.085
59783	0.015	0.000	0.000	0.014	0.000	0.000
59906	1.485	0.012	0.000	1.374	0.052	0.040
60234	0.000	0.005	0.000	0.000	0.000	0.000
60235	0.000	0.005	0.000	0.000	0.000	0.000
60236	0.000	0.005	0.000	0.000	0.000	0.000
60302	1.031	0.034	0.034	0.999	0.000	-0.022
60357	2.094	0.000	0.000	1.813	0.034	0.017
60368	1.637	0.064	0.044	1.429	0.070	0.020
60388	0.015	0.000	0.000	0.015	0.000	0.000
60589	1.614	0.013	0.000	1.575	0.000	0.000
60933	0.003	0.000	0.000	0.000	0.000	0.000
61035	0.715	0.033	0.011	0.702	0.011	0.012
61263	0.023	0.002	0.000	0.000	0.008	0.000

	HEDD Episode			Typical Episode		
ORIS	**Base case**	**All Three**	**Hope Creek**	**Base case**	**All Three**	**Hope Creek**
61282	0.076	0.003	0.003	0.066	0.003	0.000
61286	0.023	0.000	0.000	0.000	0.000	0.000
61737	0.006	0.000	0.000	0.000	0.000	0.000
61822	0.000	0.000	0.000	0.000	0.000	0.000
62741	0.001	0.000	0.000	0.000	0.000	0.000
50060	0.000	0.000	0.000	0.000	0.000	0.000
50397	0.166	0.000	0.000	0.167	0.000	0.000
54638	0.000	0.000	0.000	0.000	0.000	0.000
57407	0.038	0.000	0.000	0.038	0.000	0.000
58565	0.034	0.000	0.000	0.035	0.000	0.000

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