Analysis of the Potential Health Impacts of Reducing Ozone Levels in the OTR Using BenMAP – 2019 Edition

Includes data through 2018

Ozone Transport Commission
OTC Modeling Committee
Summer 2019

Executive Summary

In 2015, the 8-hour ozone National Ambient Air Quality Standard (NAAQS) was lowered to 70 ppb. This was the high end of the range recommended by the Clean Air Scientific Advisory Committee (CASAC) originally and in the rule proposal by Administrator McCarthy. The lower end of the range proposed by EPA was 65 ppb. Additionally, recent research has shown health effects from ozone occur at even lower levels. Given that health effects could be caused at levels closer to what is considered background we decided to also look at 40 ppb which close to a level considered to be United States Background (USB). As a result three levels of ozone were investigated in this analysis: 70 ppb, 65 ppb, and 40 ppb.

Each year that air quality does not meet the NAAQS the health of the populations exposed to the poor air quality are impacted. OTC began examining the potential health impacts of these levels of exposure starting in 2011 and as of writing 2018 is the most recent year for which data is available. As a result the analysis will focus on each ozone season for which data has been processed, 2011-2018, with the intention of adding new information annually.

Several states in the Ozone Transport Region (OTR) exceed the NAAQS set by EPA, which were set to a level to adequately protect the public health. This implies that populations in the OTR would receive a health benefit if the entire OTR were to meet the NAAQS. Additionally, even more monitors have values above the other thresholds discussed.

This paper looks at the benefits that would have occurred each year from 2011-2018, using monitored data had the entire OTR met ozone levels of 70 ppb, 65 ppb, and 40 ppb as estimated using health benefit and economic functions that came from peer reviewed sources employed by EPA in many studies processed with BenMAP.

We estimated that approximately 600 – 2,400 persons would have not died prematurely in a given year 2011-2018 had the OTR air quality attained a level that met the 70 ppb Ozone NAAQS with even more persons that would not have died if ozone levels were even lower.

As a point comparison in 2014 about 2,600 people died of homicide in the OTR and all of Virginia, 1,500 of HIV/AIDS, and 1,300 of Hepatitis C, which places deaths from ozone exposure among other notable health crises.

Additionally, we estimated that there would have been economic benefit to the region in the range of $5-19 billion in all health impacts from reducing ozone to 70 ppb in any given year.

2018 was an average year among the years analyzed. Ozone levels were high along the I-95 cooridor and to a lesser extent in Western Pennsylvania, but did not see impacts to the same extent as 2012 or 2016.

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Introduction

In 2015, the 8-hour ozone National Ambient Air Quality Standard (NAAQS) was lowered to 70 ppb.[1] This was the high end of the range recommended by the Clean Air Scientific Advisory Committee (CASAC) originally and in the rule proposal by Administrator McCarthy. The lower end of the range proposed by EPA was 65 ppb. Additionally, recent research has shown health effects from ozone occur at even lower levels.[2] Given that health effects could be caused at levels closer to what is considered background we decided to also look at 40 ppb which close to a level considered to be United States Background (USB). As a result three levels of ozone were investigated in this analysis: 70 ppb, 65 ppb, and 40 ppb.

Each year that air quality does not meet the NAAQS the health of the populations exposed to the poor air quality are impacted. OTC began examining the potential health impacts of these levels of exposure starting in 2011 and as of writing 2018 is the most recent year for which data is available. As a result the analysis will focus on each ozone season for which data has been processed, 2011-2018, with the intention of adding new information annually.

Several states in the Ozone Transport Region (OTR) had monitored design values that were above the NAAQS set by EPA. Given that the primary NAAQS are set to a level to adequately protect the public health, this implies that populations in the OTR would receive a health benefit if the entire OTR were to meet the NAAQS. This paper looks at the benefits that would have occurred each year from 2011-2018 had the entire OTR met ozone levels of 70 ppb, 65 ppb, and 40 ppb as estimated by the Environmental Benefits Mapping and Analysis Program (BenMAP) Community Edition (CE) program.[3]

Methods

Overview of the Health Impact Functions

BenMAP CE v1.4.1.14 was employed to process the health impact functions. These functions are developed to calculate the change in health incidence for a given population due to a change in air quality. The health impact functions typically consist of four variables: change in air quality, population, baseline incidence rate, and effect estimates that are drawn from epidemiological literature. The health impact functions used in the analysis were all functions provided in the downloadable version of BenMAP CE. The typical health impact function (Δy) is log-linear as follows:

$$\Delta y = y_0(e^{\beta \Delta q}-1)pop$$

where y_0 is the baseline incidence rate, β is the effect estimate, Δq is the change in air quality, and pop is the population.

[1] US EPA, "2015 National Ambient Air Quality Standards for Ozone."
[2] Di et al., "Air Pollution and Mortality in the Medicare Population."
[3] US EPA, "Environmental Benefits Mapping and Analysis Program – Community Edition: User's Manual."

Change in Air Quality

Monitored ozone data were obtained throughout the entire OTR and the states that border the region (Ohio, West Virginia, and the remainder of Virginia) for 2011-2018 from the Air Quality System (AQS) monitor network and the data was originally compiled by staff at the Maine Department of Environmental Protection. The Voronoi Neighborhood Averaging (VNA) inverse distance interpolation squared technique was used to interpolate to grid cells between monitors to the OTC 2011 based modeling platform CMAQ grid[4]. The bordering states were included so that the VNA would not result in inappropriate values along the western and southern borders of the OTR. Monitored ozone data was not available from Canada, so VNA may create unexpected results along the northern border, but exceedances are less common in that region so the monitors would not be rolled back anyway.

To avoid high levels recorded at mountain top monitors resulting in unrealistic reductions being estimated in rural New England data from several monitors (Cadillac Mountain Summit: 230090102, Mt Washington Summit: 330074001, Whiteface Mountain Summit: 360310002, and Shenandoah Big Meadows: 511130003) were removed from the data set.

Annual ozone season data was imported, but in many cases monitors only are operated during a shorter time period when conditions are conducive to ozone formation as defined in federal regulations (see Table 1). Furthermore, BenMAP requires that a certain thresholds to be met for the data at a particular monitor to be considered acceptable. The default time spans for data to be considered are too stringent since several monitors with 4th high 8-hour ozone values above 70 ppb would be excluded so the time span of May 1 – September 30 was used, with a requirement for 50% valid days. Since exceedances do occur outside of the May to September window, but within the ozone monitoring season in Table 1 there are a few instances when an exceeding monitor will not be rolled back because though there are four or more exceedances during the full ozone season, but fewer than four exceedences between May 1 and September 30. The default start and end hours were also used. 4th high 8-hour ozone data for each year can be seen in Figure 1 though Figure 8 and data for the 19 worst monitors in the OTR based on 2018 4th highest values can be seen in Table 2.

Table 1: Ozone monitoring season requirements (40 CFR 58 Appendix D (4)(i))

State	Start Date	End Date
Connecticut	March 1	September 30
Delaware	March 1	October 31
District of Columbia	March 1	October 31
Maine	April 1	September 30
Maryland	March 1	October 31
Massachusetts	March 1	September 30
New Hampshire	March 1	September 30
New Jersey	March 1	October 31
New York	March 1	October 31
Pennsylvania	March 1	October 31
Rhode Island	March 1	September 30
Vermont	April 1	September 30
Virginia	March 1	October 31

[4] Ozone Transport Commission, *Technical Support Document for the 2011 Ozone Transport Commission/Mid-Atlantic Northeastern Visibility Union Modeling Platform - 2nd Revision*.

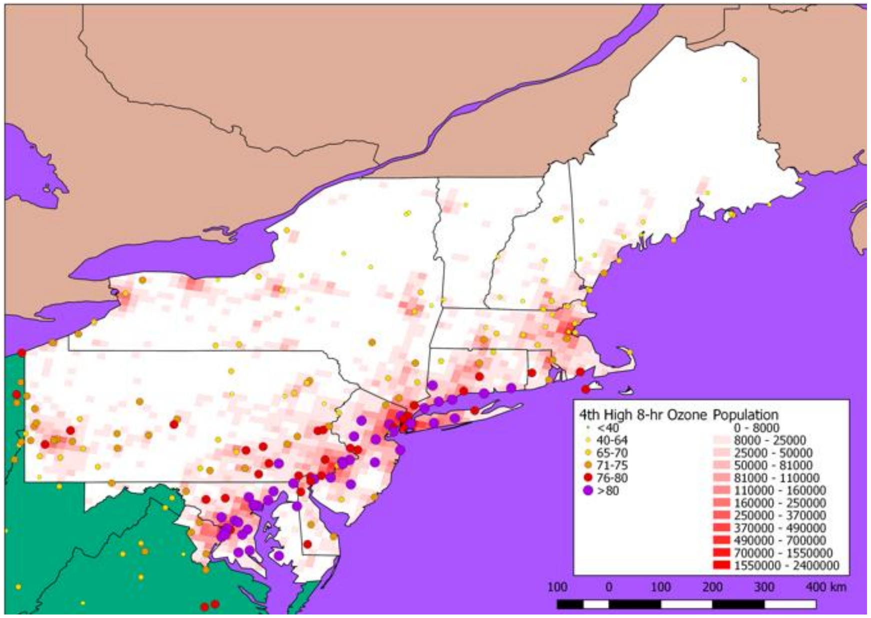


Figure 1: 4th high monitored 8-hour ozone values and gridded population for 2011

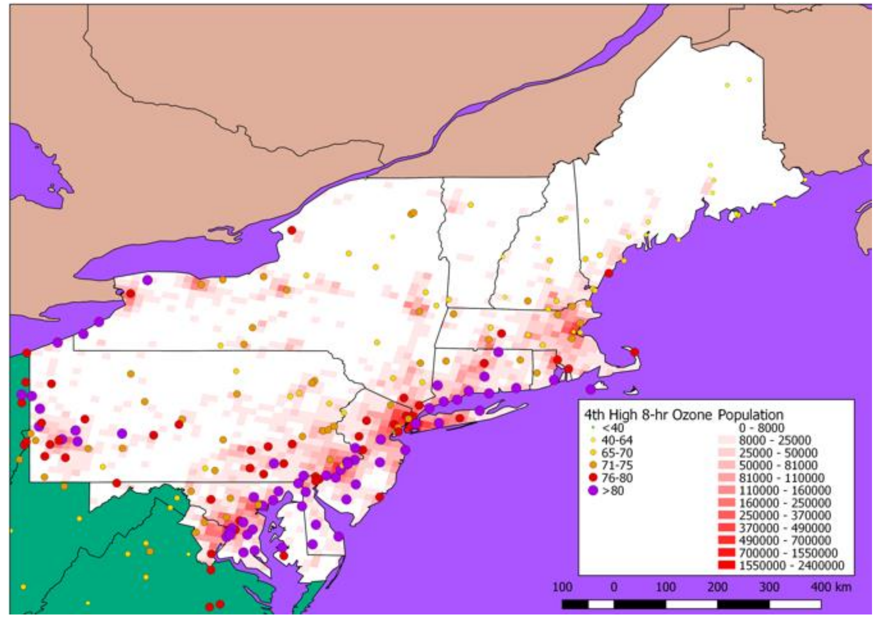


Figure 2: 4th high monitored 8-hour ozone values and gridded population for 2012

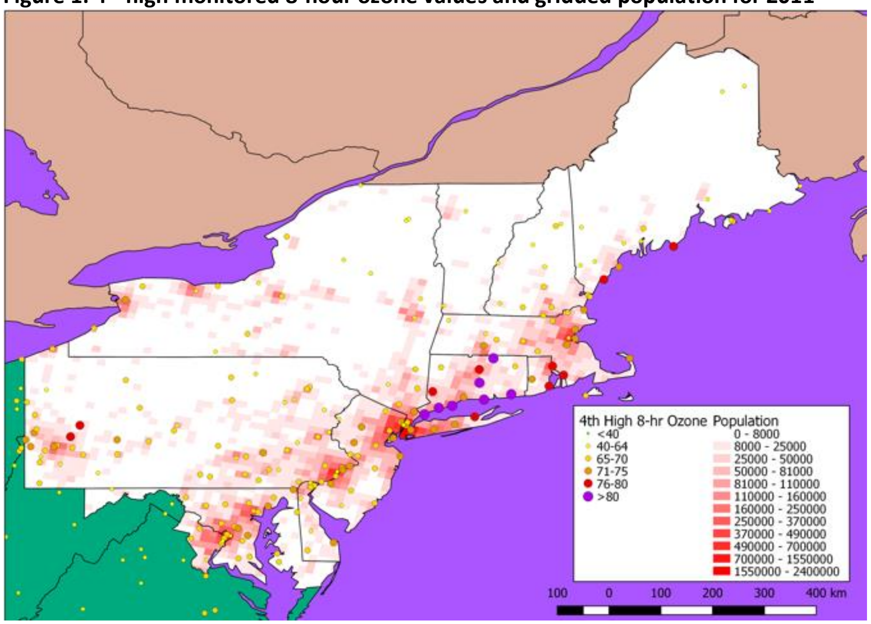


Figure 3: 4th high monitored 8-hour ozone values and gridded population for 2013

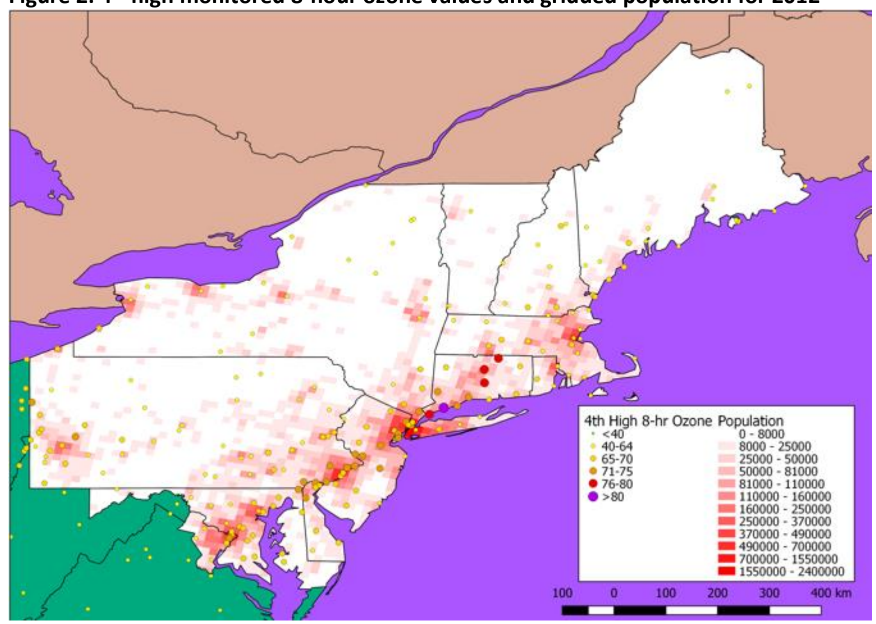


Figure 4: 4th high monitored 8-hour ozone values and gridded population for 2014

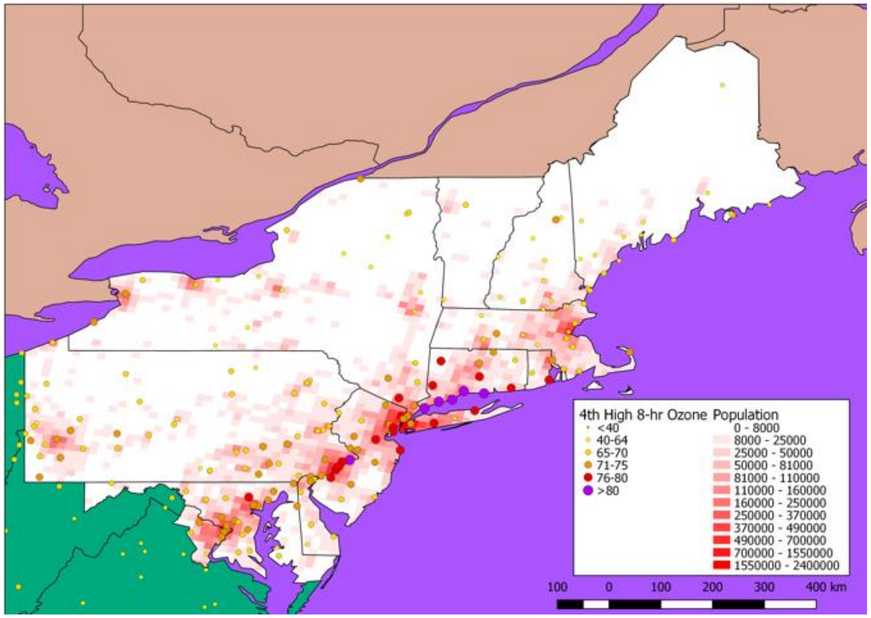


Figure 5: 4th high monitored 8-hour ozone values and gridded population for 2015

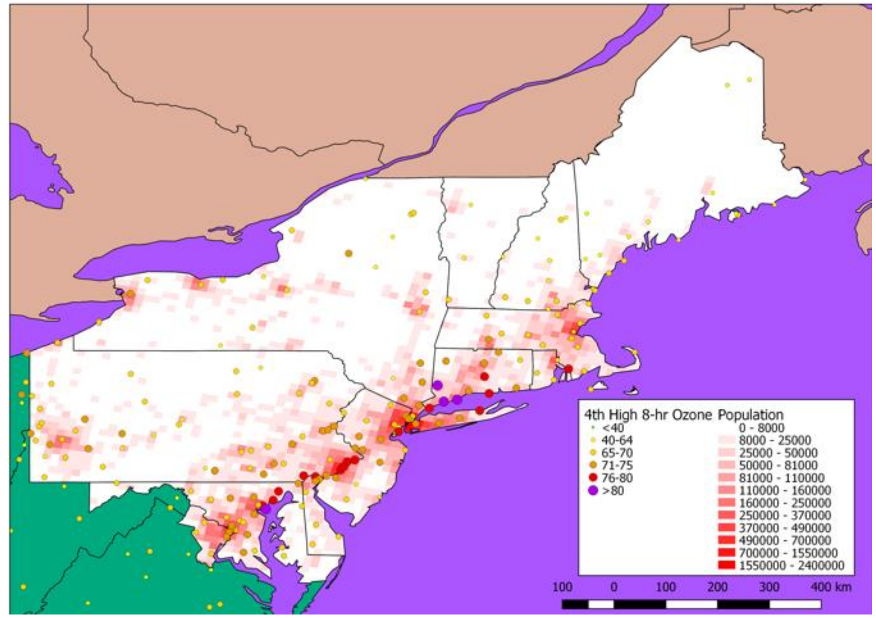


Figure 6: 4th high monitored 8-hour ozone values and gridded population for 2016

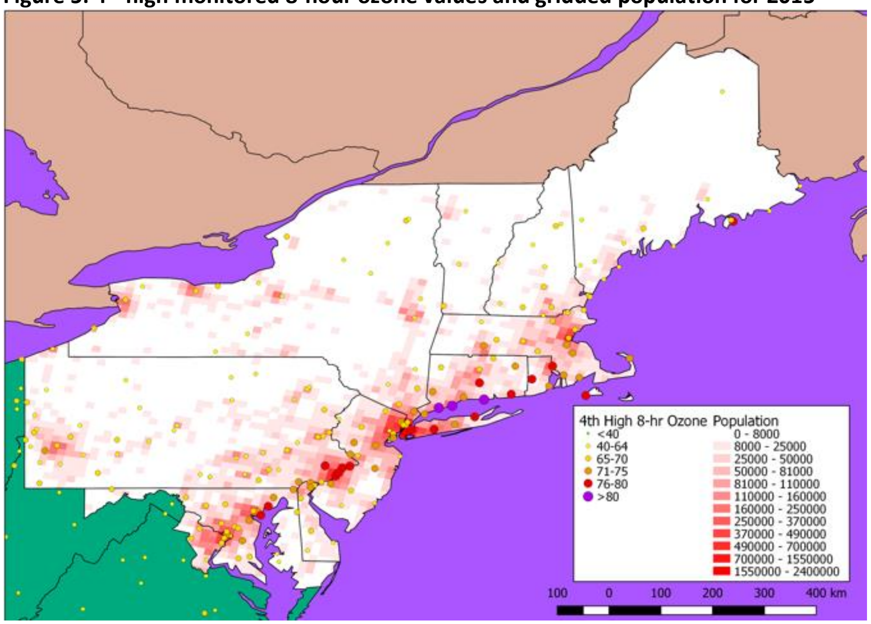


Figure 7: 4th high monitored 8-hour ozone values and gridded population for 2017

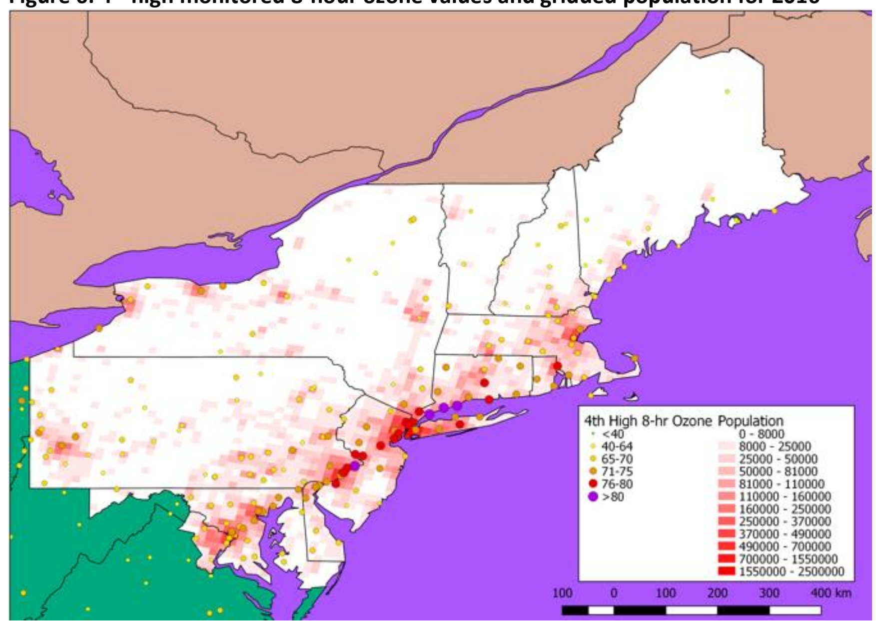


Figure 8: 4th high monitored 8-hour ozone values and gridded population for 2018

Table 2: 4th Highest 8-hour Ozone Concentrations from 2011 – 2018 (Ordered by 2018 Concentrations)

Agency	Site Name	AQS Code	4th Highest 8-hr Ozone Concentrations							
			2011	2012	2013	2014	2015	2016	2017	2018
CT	Greenwich	90010017	81	88	82	78	84	79	74	86
CT	Westport	90019003	87	89	86	81	87	81	81	84
PA	Bristol	420170012	81	82	73	71	82	80	79	84
CT	Stratford	90013007	87	90	90	74	86	83	81	83
NJ	Leonia	340030006	82	76	74	73	76	73	74	79
PA	NEA	421010024	89	85	68	72	79	80	76	79
RI	E Providence	440071010	73	79	76	64	71	64	76	79
NJ	Bayonne	340170006	78	74		72	77	68	67	78
NY	White Plains	361192004	76	79	72	74	73	75	72	78
CT	Middletown-combined	90079007	80	81	82	80	78	80	79	77
CT	Madison-combined	90099002	92	90	85	69	81	80	86	77
NJ	Clarksboro	340150002	92	87	73	70	76	74	73	77
NJ	Wash Crossing	340219991	80	81	69	71	75	74	71	77
NY	NYC-Pfizer Lab-combined	360050133	79	76	68	70	72	70	69	77
NY	NYC	360610135	80	74	62	65	71	71	70	77
NY	Fresh Kills	360850111								77
NJ	Rider U	340210005	79	80	70	71	73	71	69	76
NJ	Rutgers U	340230011	87	82	70	71	77	75	75	76
NY	Holtsville-combined	361030009	82	79	74	62	63	73	71	76

After importing each year's monitored ozone data, BenMAP CE was employed to conduct an analysis termed "roll back." In this approach a mathematical technique is used to reduce the ozone values at the monitors so that each meets a threshold, in these cases a 4th highest daily maximum 8-hour ozone average concentration of 70 ppb, 65 ppb, or 40 ppb. Technically to demonstrate compliance with the 8-hour ozone NAAQS, the average of 3 years of the 4th highest daily maximum 8-hour ozone averages is calculated and referred to as a design value (DV) This is necessary since BenMAP CE only accepts one year worth of air quality data in an analysis. After the "roll back" is complete, the monitor data was then interpolated geographically using an inverse distance weighting technique.

There are three techniques for rolling back the monitored values to the standard: percentage reduction, incremental, and peak shaving that need to be applied to the inter-day and intra-day rollback. The peak shaving technique was employed for the inter-day rollback so values meeting the standard would not have reductions applied, which would result in more conservative results. The percentage technique was employed for the intra-day rollback since it best reflected the implementation of measures that would affect each hour of the day equally.

In conducting the analysis, including a background rate was necessary to prevent monitors from being lowered below what would occur absent anthropogenic emissions. There are a variety of estimates for background, and even several values considered background (e.g., United States Background (USB) and North American Background (NAB). For this aspect of the modeling a value of 30 ppb was used which is associated with lower levels of NAB found in the Eastern United States in the summer time as was presented in Figure 3-9 of EPA's Integrated Scientific Assessment for the 2015 Ozone NAAQS.[5] Peak shaving was used as the inter-day rollback method and percentage reduction was used as the intra-day rollback method. In both cases 30 ppb was used for the background level.

[5] Lin Zhang et al., "Improved Estimate of the Policy-Relevant Background Ozone in the United States Using the GEOS-Chem Global Model with 1/2° × 2/3° Horizontal Resolution over North America"; US EPA, *Integrated Science Assessment for Ozone and Related Photochemical Oxidants*.

One potential flaw with the rollback approach is that only monitors that have 4th highest values above 70 ppb were rolled back to the standard. However, in a case where controls are put on to achieve such a monitored level, downwind areas would also have reduced ozone concentrations even though their monitors are already below the standard. As a result, the health effects downwind, in New England in particular, are lower than what would be experienced in a real world scenario.

Population

US population data were based on estimates of populations in the corresponding year projected from 2010 block-level US Census data. The geographic extent of population was limited to the population that lives in the 12 full states in the OTR, the District of Columbia and the nine cities/counties in Virginia that are considered part of the OTR. However, not all health incidence are evaluated against the entire population of the OTR, some are evaluated only against sub populations based on age. The total population used for each year and various age cohorts as well as the health endpoint group associated with the age cohort is in Table 3. A similar breakdown by state is available upon request.

Table 3: Population for each age cohort by year analyzed (millions people)

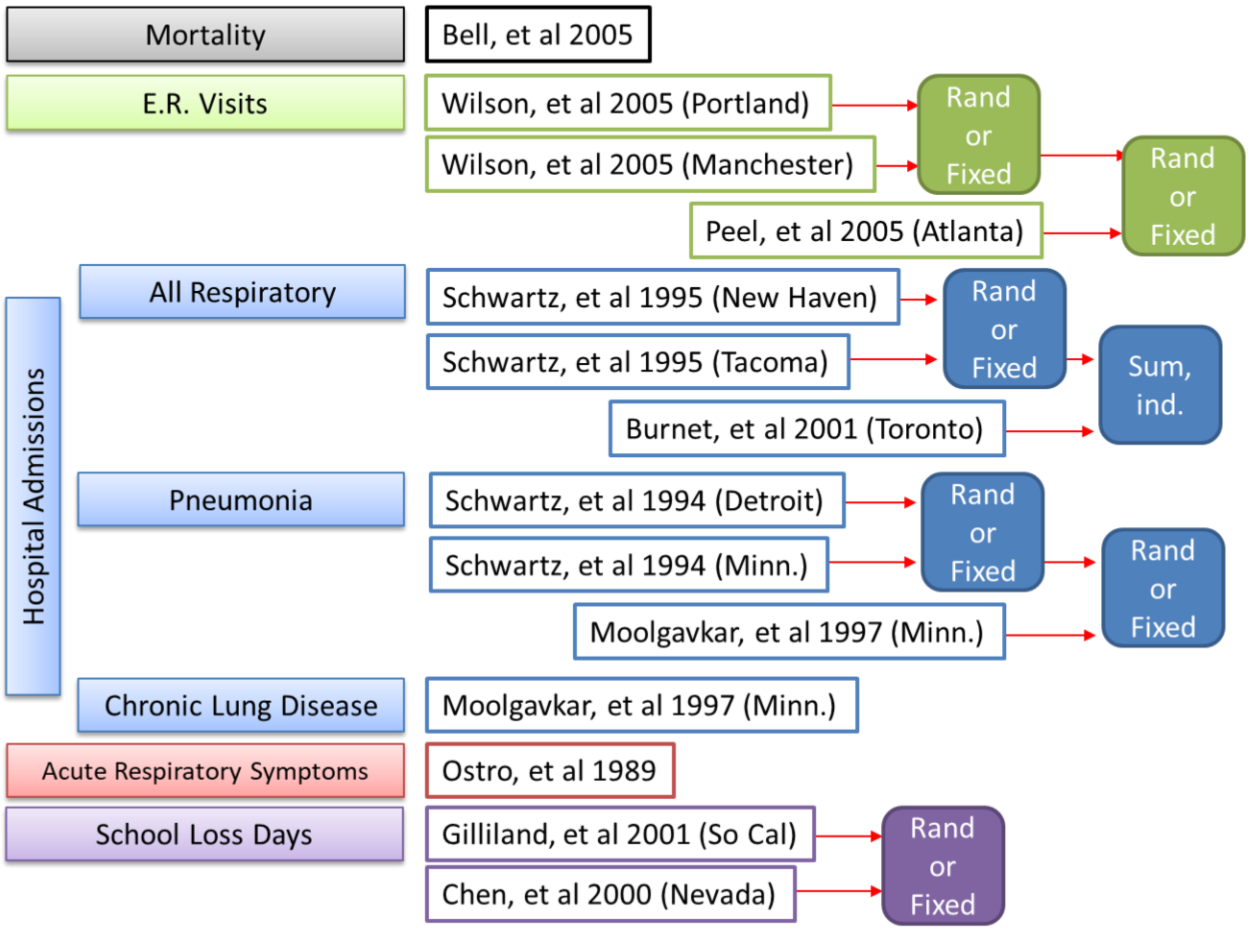
	Ages	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**
Mortality									
Mortality, All Cause	*All*	65.79	66.10	66.40	66.61	66.93	67.30	67.68	68.06
Emergency Room Visits									
Asthma	*All*	65.79	66.10	66.40	66.61	66.93	67.30	67.68	68.06
Hospital Admissions									
All Respiratory	*0-1*	5.34	5.50	5.64	5.77	5.92	6.08	6.23	6.39
Chronic Lung Disease	*65+*	9.12	9.46	9.74	9.99	10.26	10.53	10.82	11.12
Pneumonia	*65+*	9.12	9.46	9.74	9.99	10.26	10.53	10.82	11.12
Acute Respiratory Symptoms									
Minor Restricted Activity Days	*18-64*	41.97	42.02	42.12	42.15	42.25	42.32	42.36	42.38
School Loss Days									
School Loss Days, All Cause	*5-17*	10.82	10.75	10.68	10.59	10.50	10.46	10.45	10.44

Selection of Health Impact Functions

There is evidence of a relationship between long-term exposure to concentrations of ozone and premature respiratory mortality, which is one of a few studies that detect an increase in mortality from long-term ozone exposure.[6] However there remain questions as to whether long-term mortality has the same direct relationship to ozone exposure as short-term mortality does since this is a newer finding in the literature, so this paper will only examine short-term mortality. Additionally, several functions representing morbidity, including acute respiratory symptoms, respiratory hospital admissions, respiratory emergency rooms visits, and school loss days, were used, which are functions typically used in EPA studies. The process to aggregate the results of the health studies is in Figure 9.

[6] Jerrett et al., "Long-Term Ozone Exposure and Mortality."

Figure 9: Aggregation of health effects studies



Baseline Incidence Rates

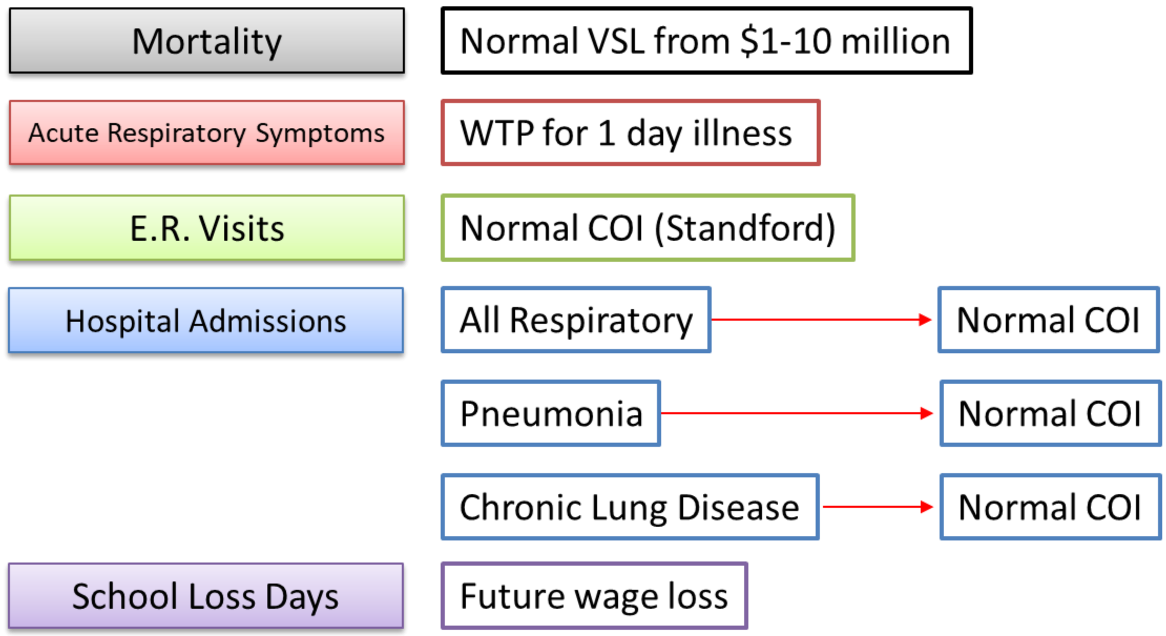
Baseline incidence rates that are part of EPA's dataset were used in this analysis. Incidence rate data sets are not available for every year so selections of which year to use are largely made based on the proximity of the year the incidence data set is for to the year of the monitored data being evaluated. Projections of mortality incidence rates were available in five-year increments and 2015, which coincided with one of the years analyzed, was determined to be the most appropriate data set to use with the mortality health impact functions. Only one incidence data set was available for the other health endpoints so the incidence estimates for 2014 were used for the other health endpoints excepting school loss days where 2000 was the only data set available and acute respiratory systems which has a slightly different form than the other functions, so baseline incidence rates are not included in the equation.

Economic Analysis

In order to quantify the impact of the health benefits the reduced incidence is multiplied by a valuation estimated through one of several techniques. In the case of mortality, the Value of Statistical Life (VSL) based upon a normal distribution was used. The VSL uses differences in salaries and the inherent risk of a job to infer the rate at which life is valued. A Willingness to Pay (WTP) estimate was used to monetize acute respiratory symptoms. WTP relies on survey data to determine how much people value not having an adverse health effect. Cost of Illness (COI) estimates were used to value emergency room visits and hospital admissions. COI totals up the amount spent on medicine, hospital visits, etc. due to an adverse heath effect. Since the VSL is based on hedonic economic analysis it best characterizes the complete value of the effect, with the WTP estimates characterizing less of the true cost, and COI capturing the least of the true cost. The process undertaken to aggregate the economic results are in Figure 10.

Additionally, income effects were adjusted to the year analyzed and all valuations are in 2010 U.S. Dollars, inflated using the Consumer Price Index (CPI) and Employer Costs for Employee Compensation (ECEC).

Figure 10: Aggregation of economic evaluations



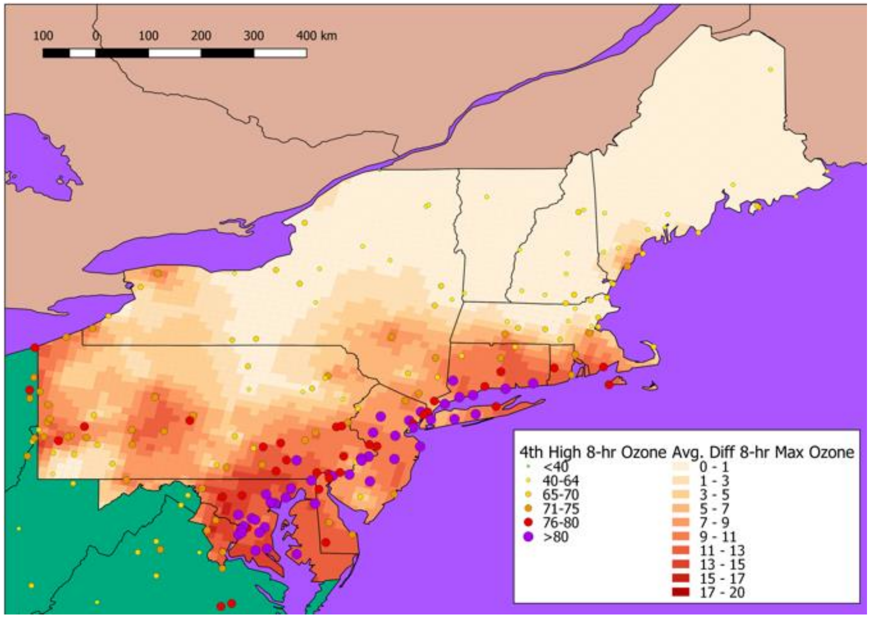


Figure 11: Change in avg. 8-hour max. ozone after roll back to 70ppb using 2011 data

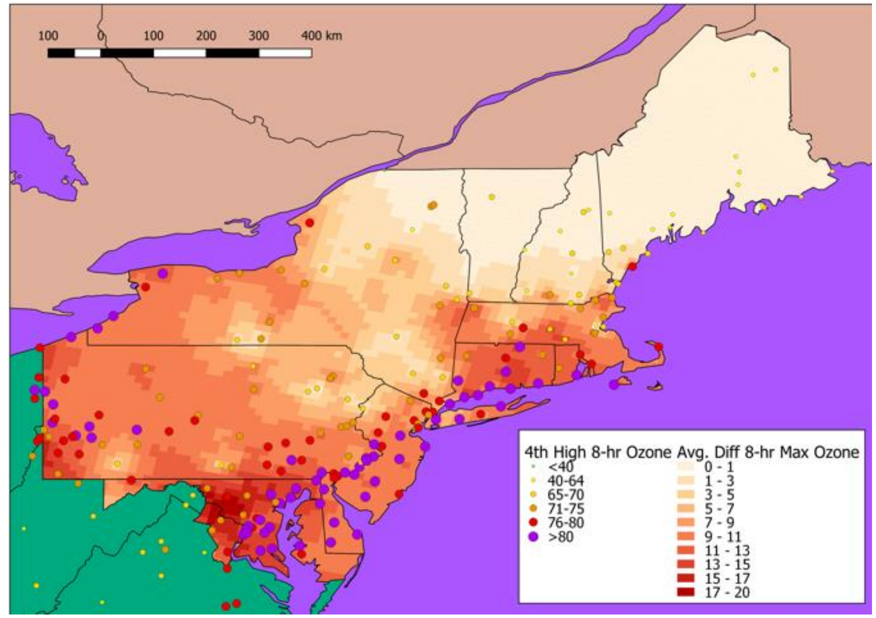


Figure 12: Change in avg. 8-hour max. ozone after roll back to 70ppb using 2012 data

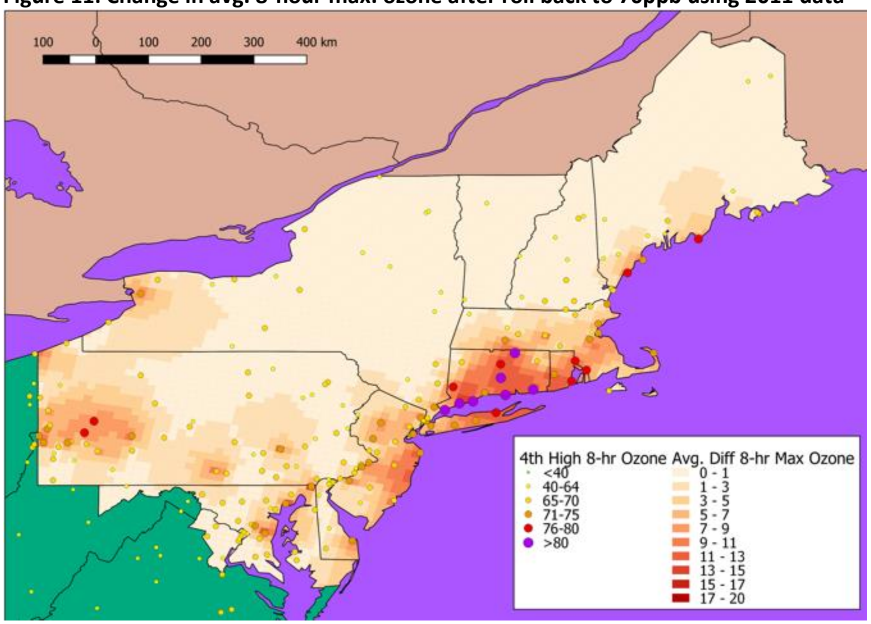


Figure 13: Change in avg. 8-hour max. ozone after roll back to 70ppb using 2013 data

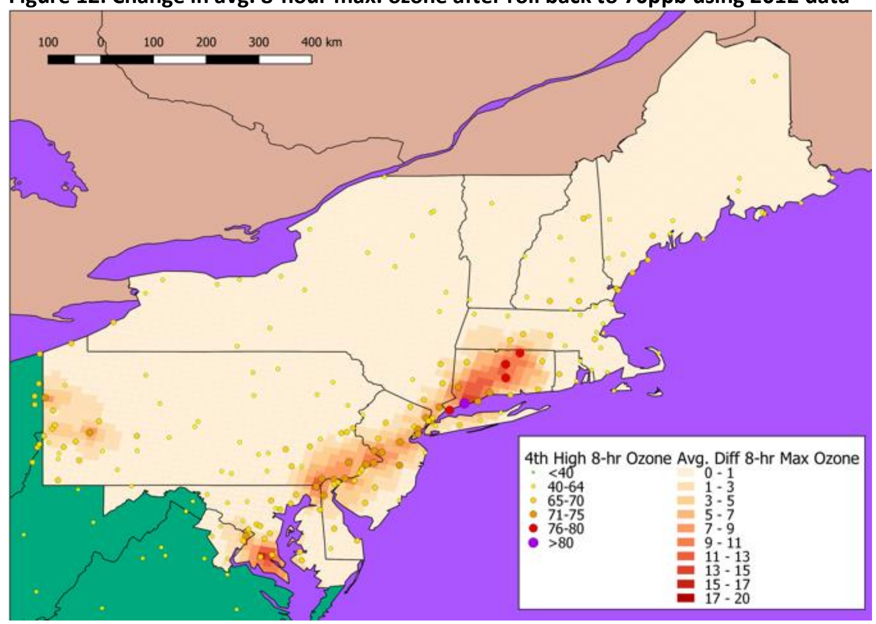


Figure 14: Change in avg. 8-hour max. ozone after roll back to 70ppb using 2014 data

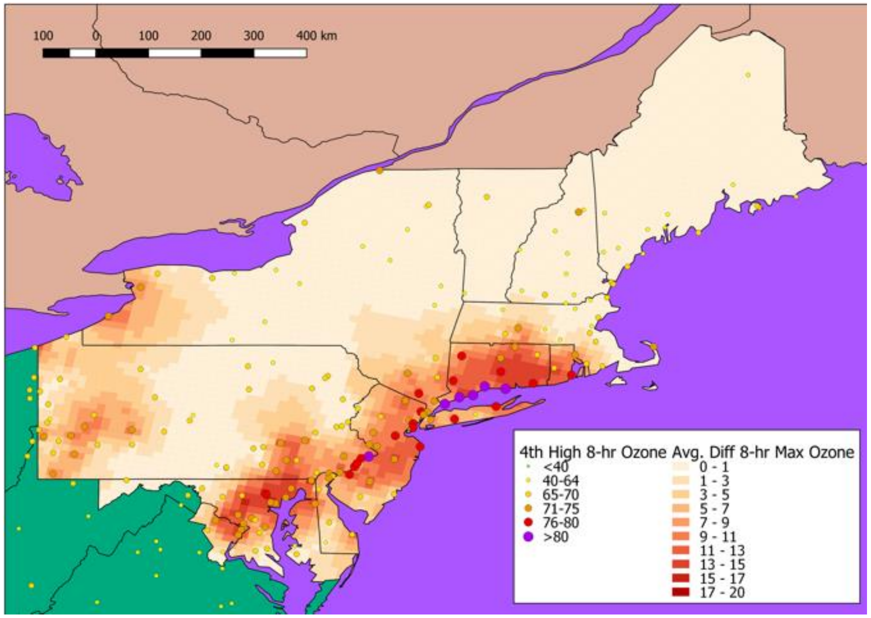


Figure 15: Change in avg. 8-hour max. ozone after roll back to 70ppb using 2015 data

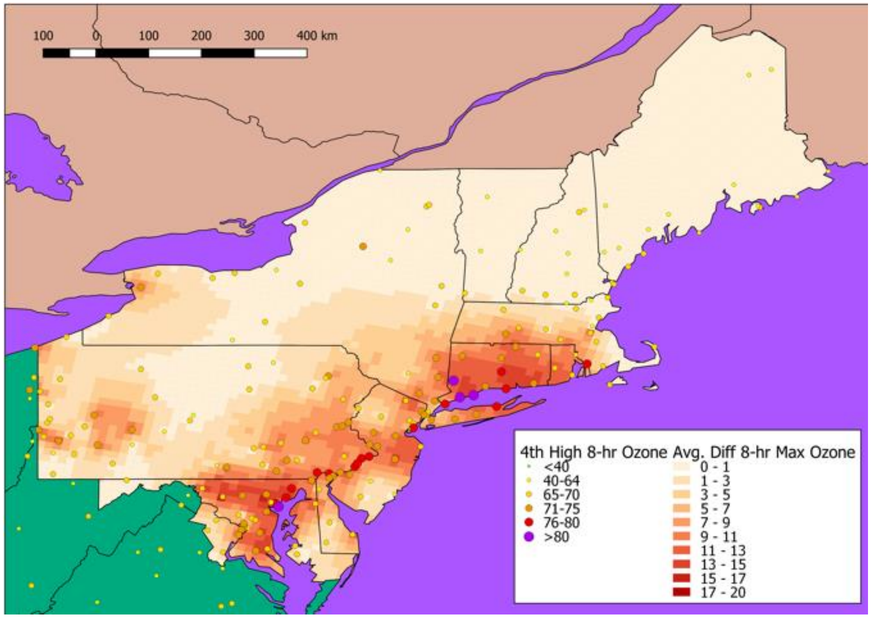


Figure 16: Change in avg. 8-hour max. ozone after roll back to 70ppb using 2016 data

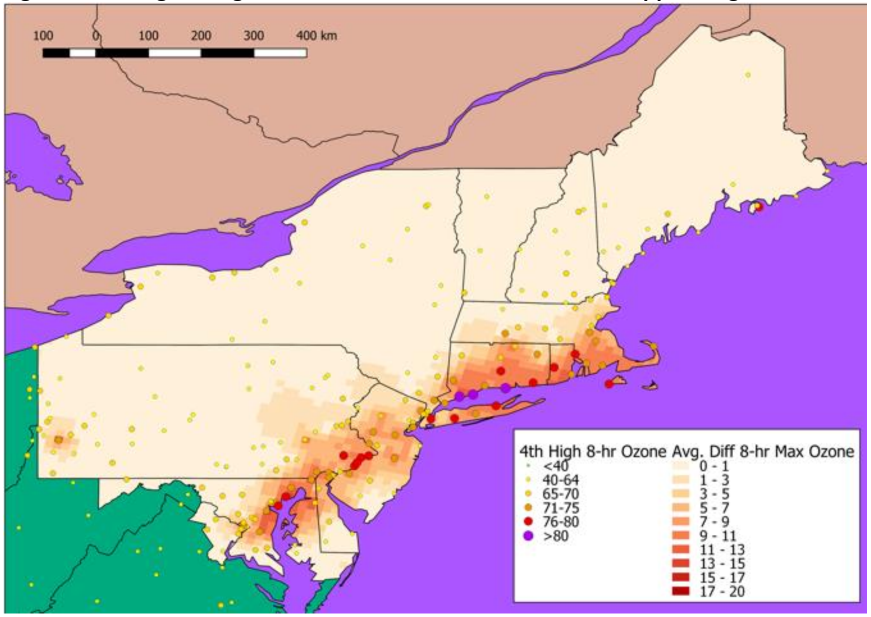


Figure 17: Change in avg. 8-hour max. ozone after roll back to 70ppb using 2017 data

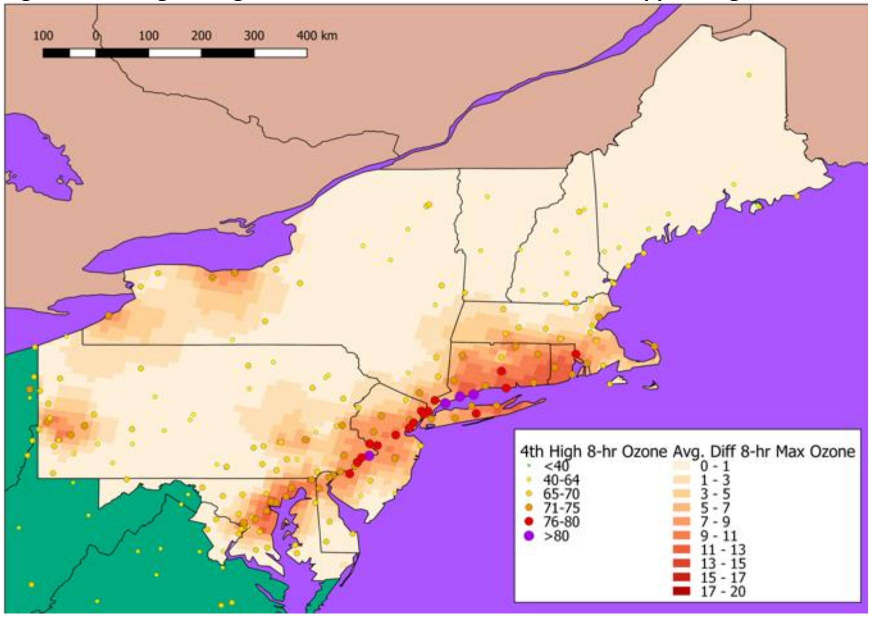


Figure 18: Change in avg. 8-hour max. ozone after roll back to 70ppb using 2018 data

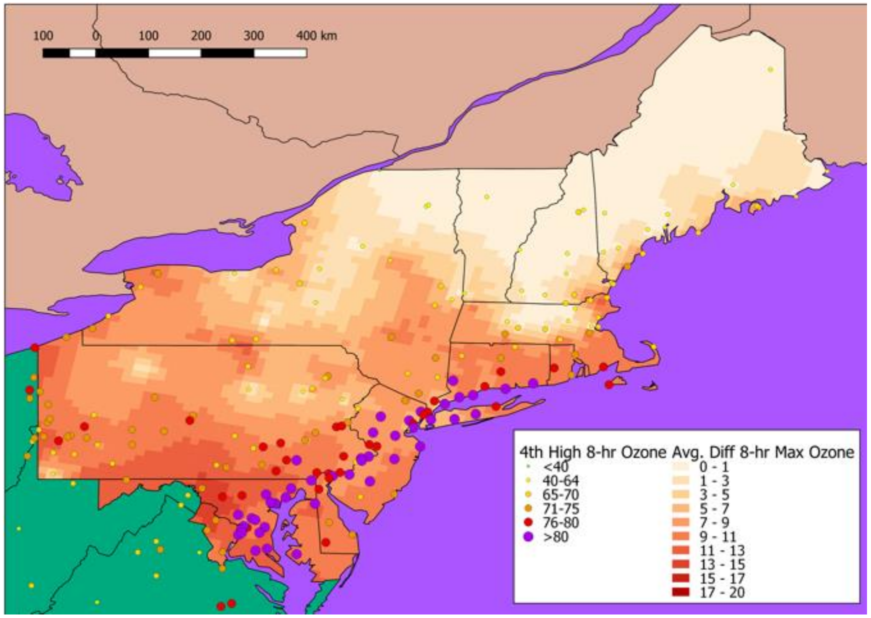


Figure 19: Change in avg. 8-hour max. ozone after roll back to 65ppb using 2011 data

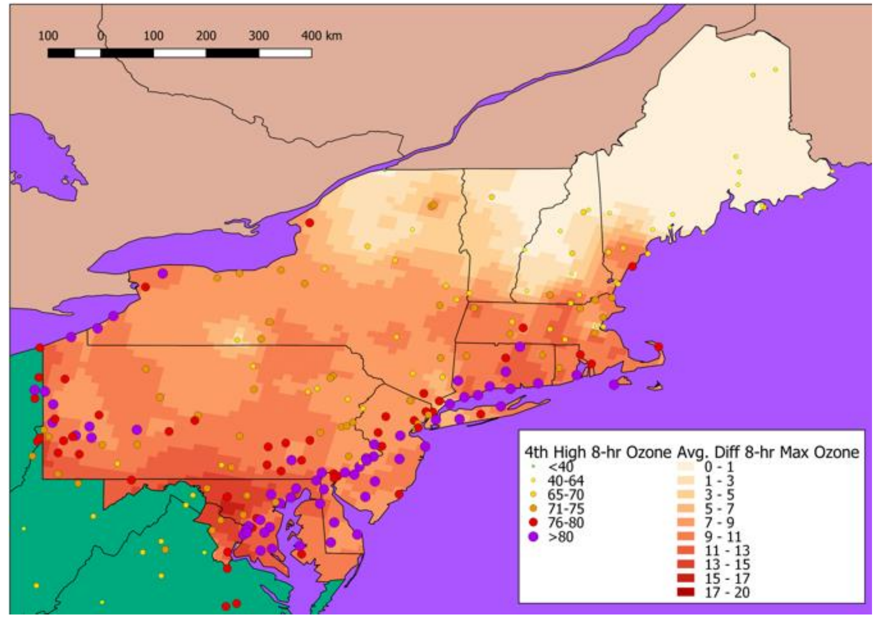


Figure 20: Change in avg. 8-hour max. ozone after roll back to 65ppb using 2012 data

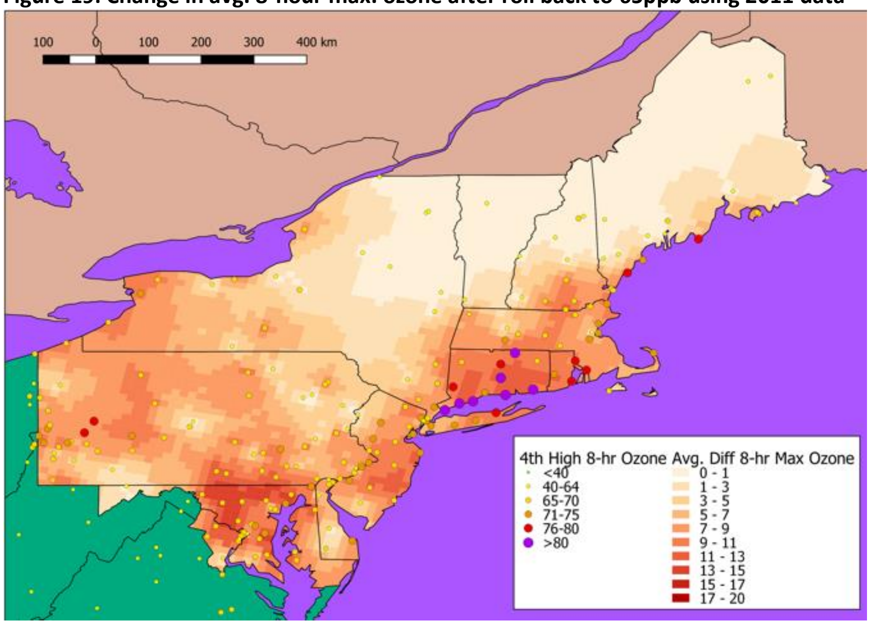


Figure 21: Change in avg. 8-hour max. ozone after roll back to 65ppb using 2013 data

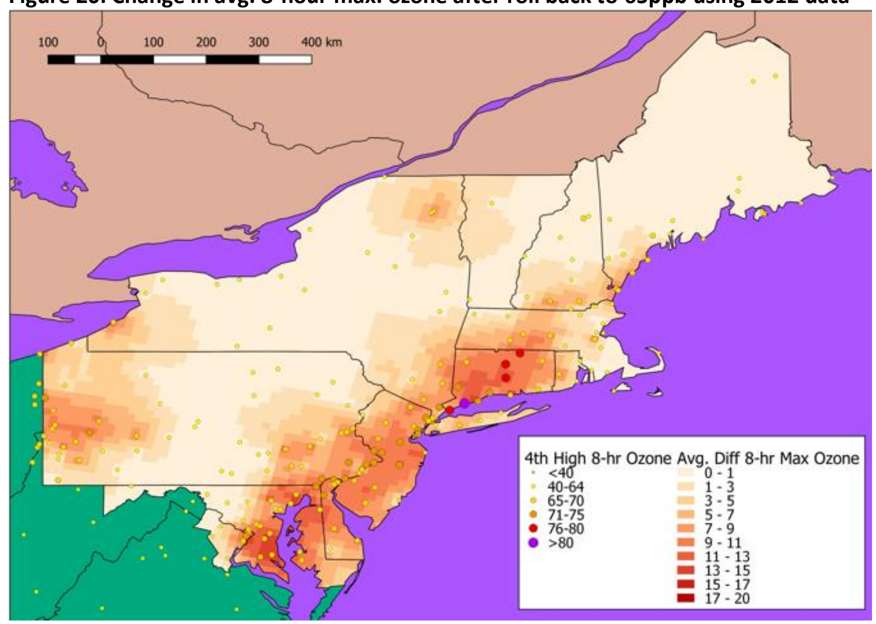


Figure 22: Change in avg. 8-hour max. ozone after roll back to 65ppb using 2014 data

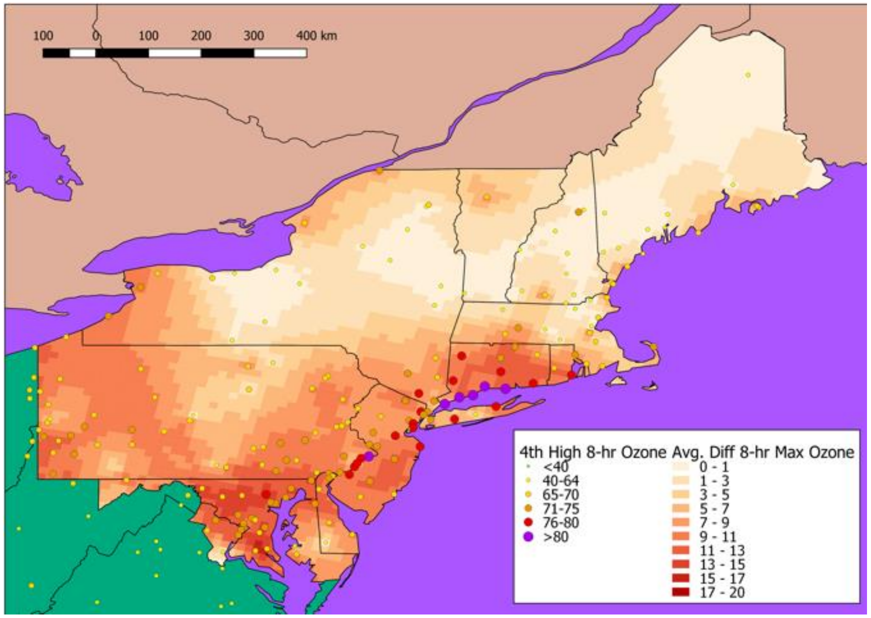


Figure 23: Change in avg. 8-hour max. ozone after roll back to 65ppb using 2015 data

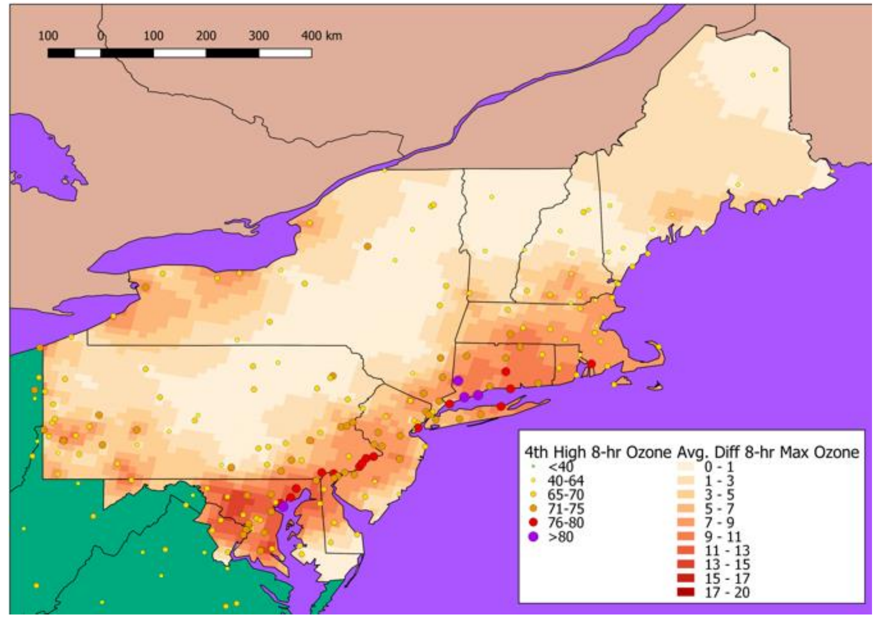


Figure 24: Change in avg. 8-hour max. ozone after roll back to 65ppb using 2016 data

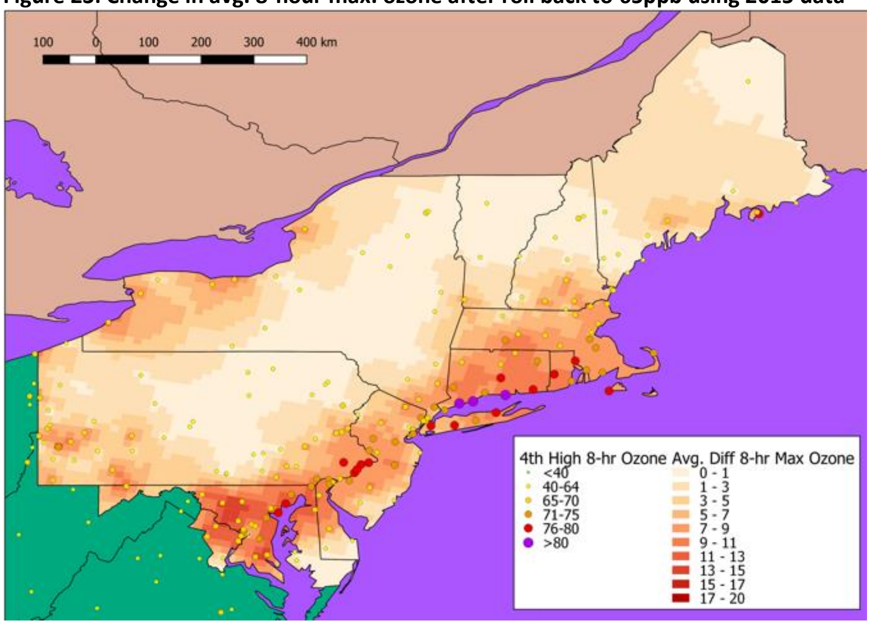


Figure 25: Change in avg. 8-hour max. ozone after roll back to 65ppb using 2017 data

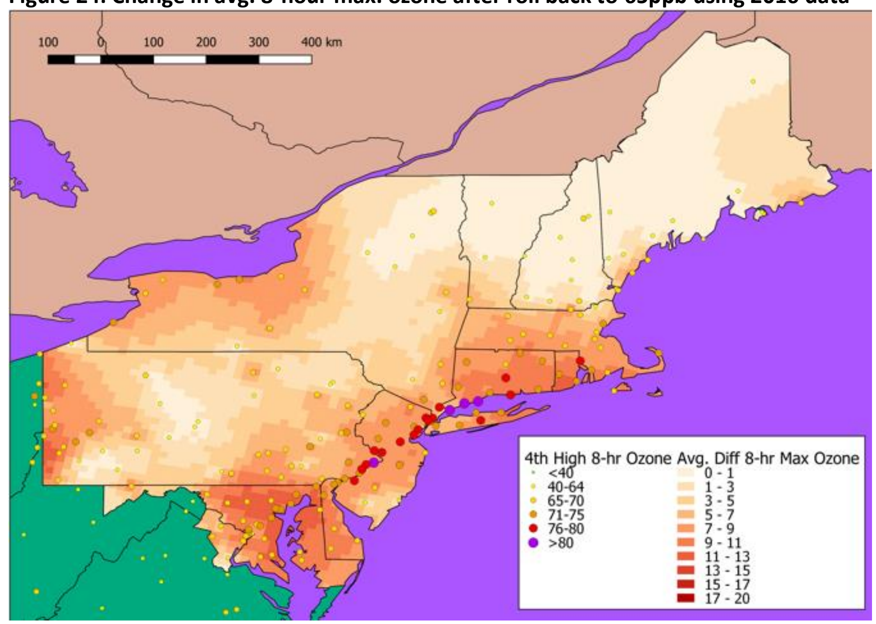


Figure 26: Change in avg. 8-hour max. ozone after roll back to 65ppb using 2018 data

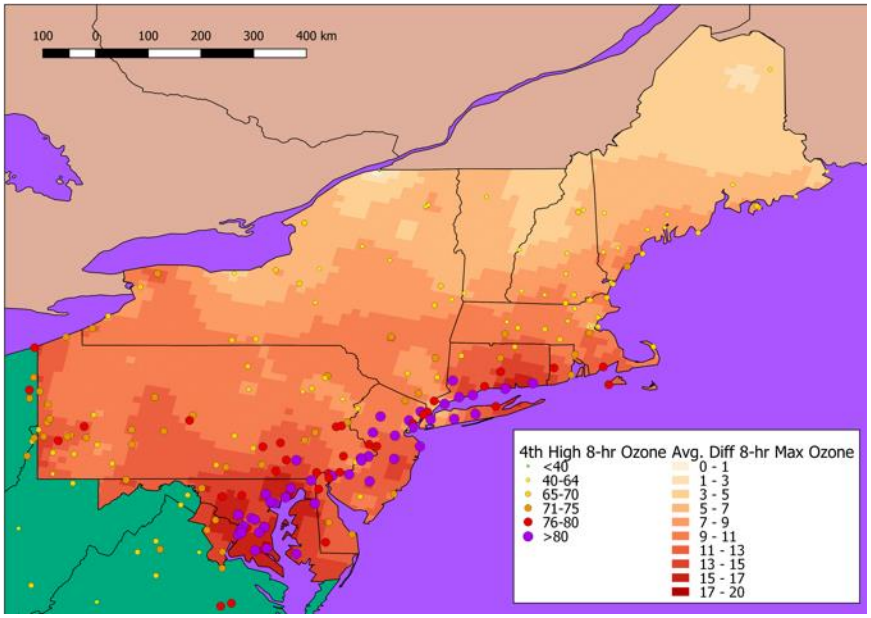


Figure 27: Change in avg. 8-hour max. ozone after roll back to 40ppb using 2011 data

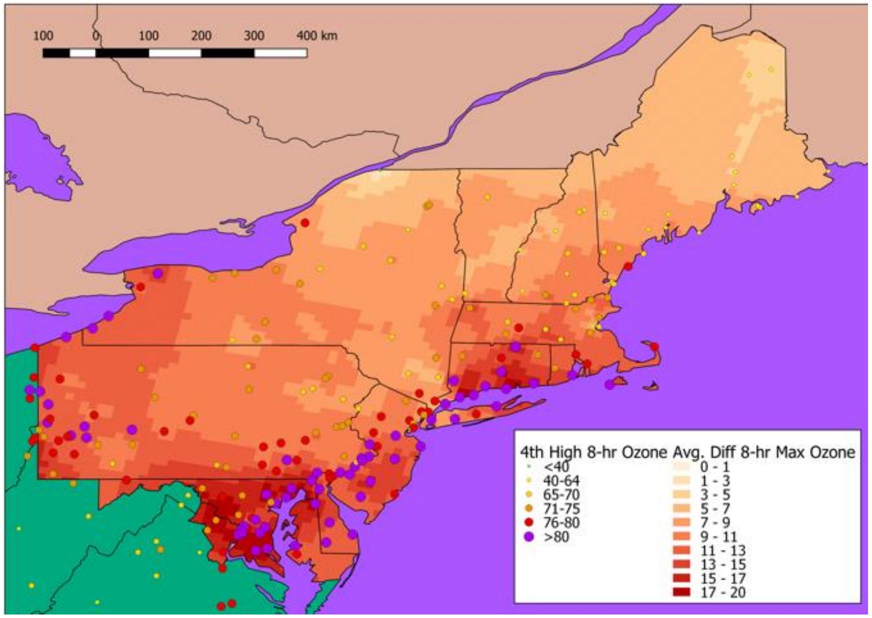


Figure 28: Change in avg. 8-hour max. ozone after roll back to 40ppb using 2012 data

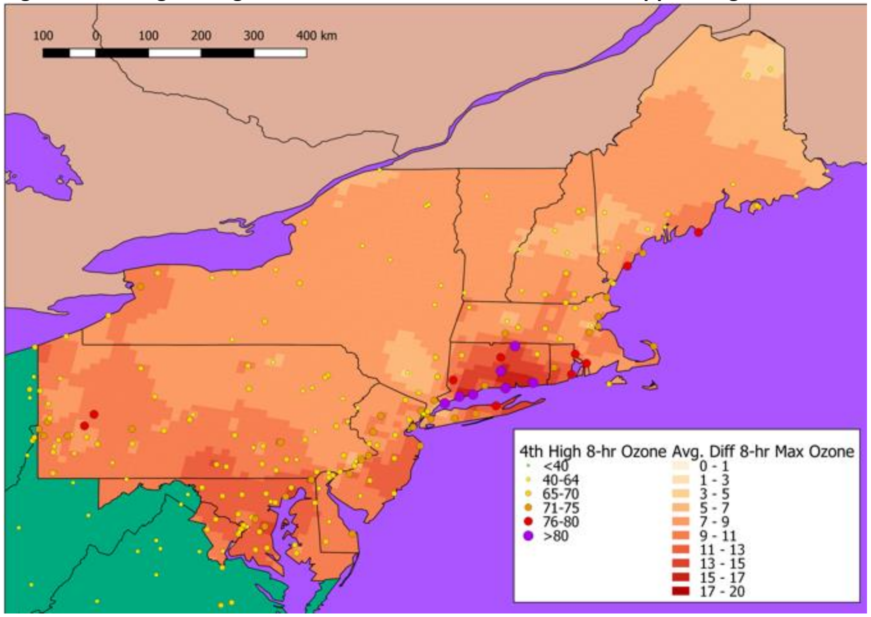


Figure 29: Change in avg. 8-hour max. ozone after roll back to 40ppb using 2013 data

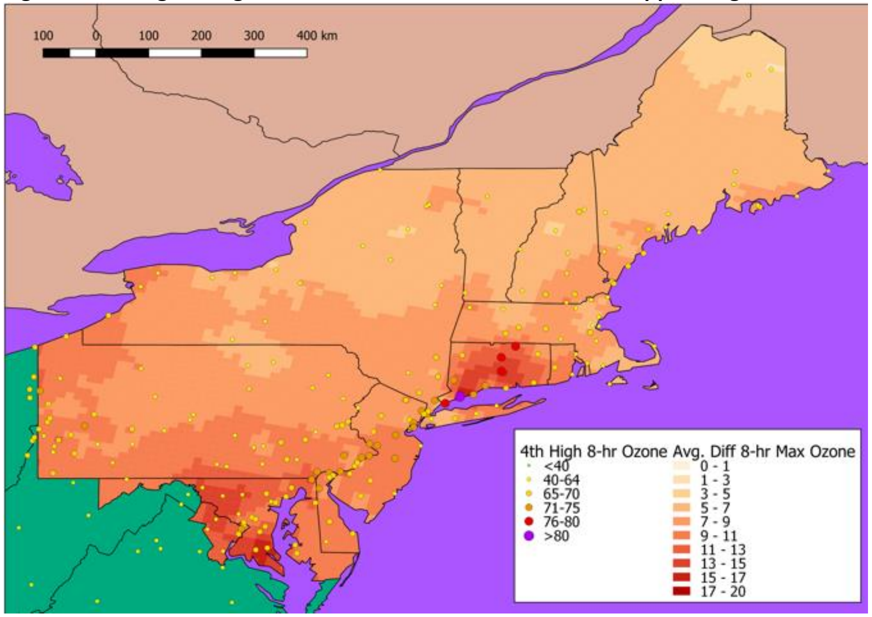


Figure 30: Change in avg. 8-hour max. ozone after roll back to 40ppb using 2014 data

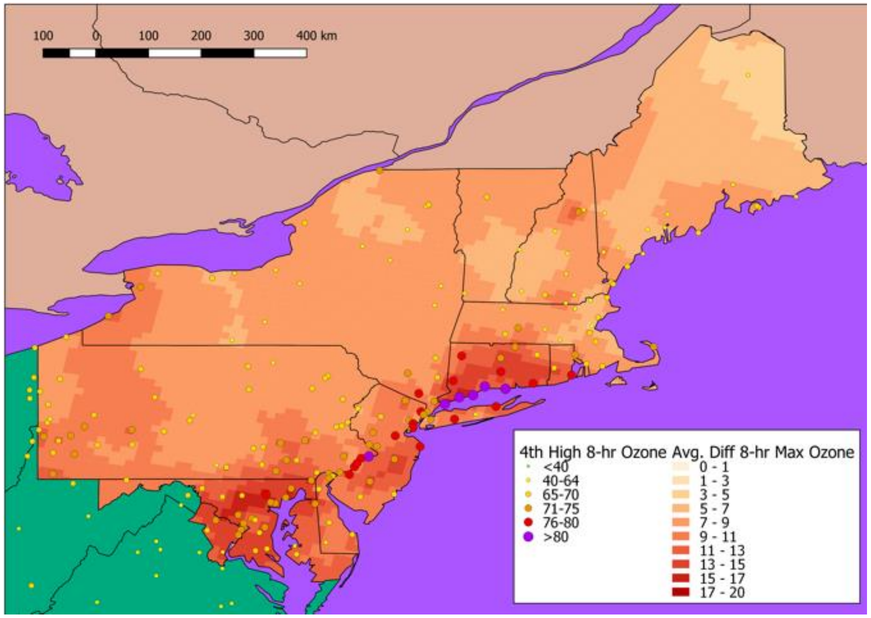


Figure 31: Change in avg. 8-hour max. ozone after roll back to 40ppb using 2015 data

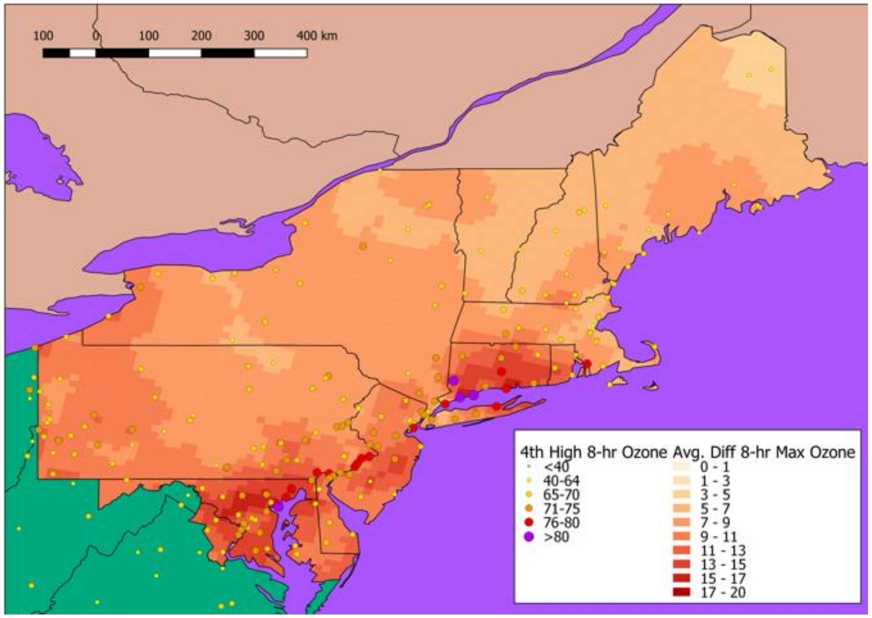


Figure 32: Change in avg. 8-hour max. ozone after roll back to 40ppb using 2016 data

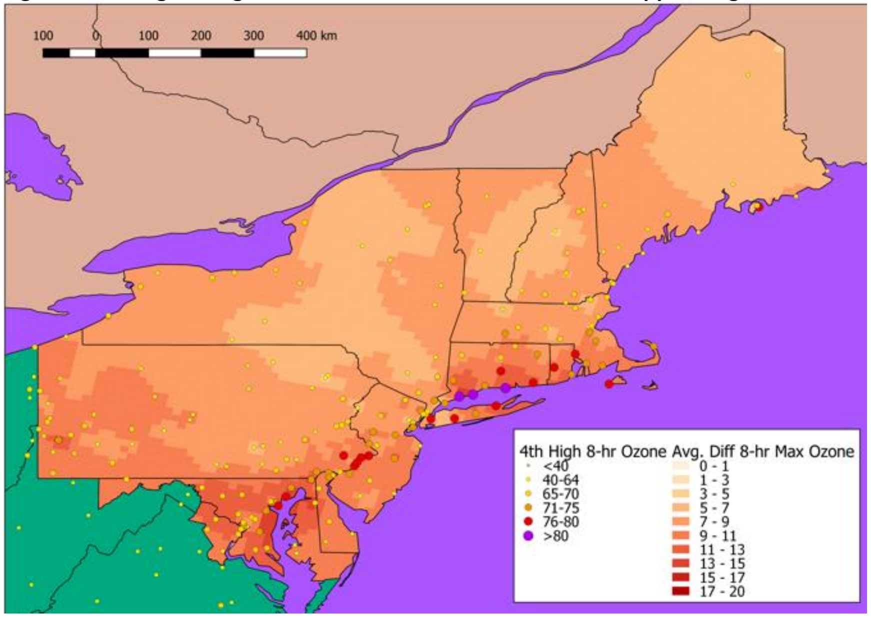


Figure 33: Change in avg. 8-hour max. ozone after roll back to 40ppb using 2017 data

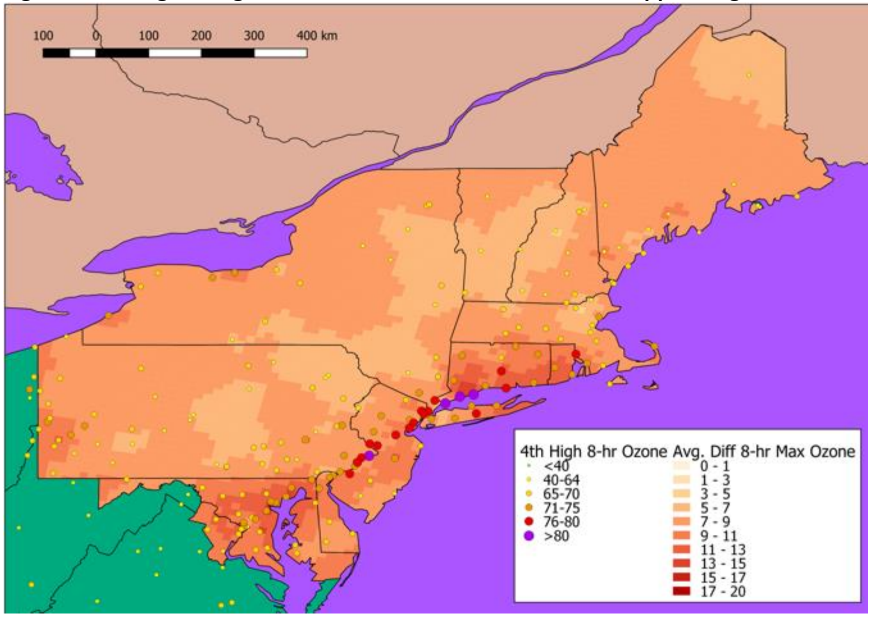


Figure 34: Change in avg. 8-hour max. ozone after roll back to 40ppb using 2018 data

Results

Monitor Rollback

Overview maps of the changes in average 8 hour maximum ozone concentrations in the OTR after being rolled back to 70 ppb (Figure 11 through Figure 18), to 60 ppb (Figure 19 through Figure 26), and to 40 ppb (Figure 27 through Figure 34).

The majority of the reductions in ozone levels in 70 ppb rollbacks occurred in the I-95 corridor between Washington, DC and New York City, NY, with smaller reductions extending north to Boston, MA. In years with higher ozone overall, the reductions in and along the corridor were of higher magnitude.

Reductions were most widespread in 2012 (Figure 12) when they extended throughout Central Pennsylvania, New York, Massachusetts, and southern Northern New England. Reductions in 2011 (Figure 11) were also widespread, though did not extend to North Central New York, Southern Vermont, nor Southern New Hampshire. The least reductions were seen in 2014 (Figure 14), when even the Baltimore area saw no reductions.

The Pittsburgh area also saw reductions in the 70 ppb rollback scenarios except in 2014 (Figure 14). Isolated areas in Western New York and Central Pennsylvania also saw reductions in 2013 (Figure 13), 2015 (Figure 15), and 2016 (Figure 16).

In the 65 ppb scenarios for 2013 (Figure 21) through 2018 (Figure 26), the results resembled those in the 70ppb scenario for 2011 and 2012. In 2011 (Figure 19) and 2012 (Figure 20) rolling back monitors to 65 ppb did not increase the geography that saw reductions much from the 70 ppb roll back scenario, with one exception is that in many of the 65 ppb scenarios Northern New York and Northern New England did begin to see reductions in ozone levels. Though there were not many difference for the 70 ppb rollback between the 2018 (Figure 18) and 2017 (Figure 17) rollbacks the 2018 rollback for 65 ppb (Figure 26) saw more reductions than the 2017 rollback (Figure 25).

The entire region saw massive reductions in ozone levels in the 40 ppb rollback scenarios including many rural areas in the region, with the least reductions occurring in Northern New York and Northern New England and the greatest reductions again along the I-95 corridor.

Health Impact

After processing the health impact functions, we estimated that had the entire OTR had 4th highest monitor results at or under 70 ppb it is expected that there would have been anywhere from 600 to 2,400 fewer short term mortalities due to ozone exposure in a given year (Table 4). As would be expected from the reductions in ozone levels 2012 saw the most mortalities that could have been prevented had a 70 ppb NAAQS been achieved and 2014 saw the least.

To put these numbers into perspective in 2014 the 33rd highest cause of mortality was homicide in the OTR+VA, which lead to 2,599 deaths, and the 47th highest cause of mortality was rheumatic heart conditions, which lead to 617 deaths (Table 6). Other causes of mortality that fall into this range are oral cancer (1,763), HIV/AIDs (1,547), alcohol (1,492), and skin disease (995).

With one exception, more mortality was modeled to have been prevented from achieving a level of 65 ppb. The largest increases in magnitude (nearly doubling) of decreased mortalities were in the years (e.g., 2013, 2015, 2017) with the lowest decreases in mortality in the 70 ppb scenario. Years (e.g., 2011, 2015, 2016, and 2018) with higher magnitudes of decreased mortality in the 70 ppb did not see the same doubling of benefits in reduced mortality from achieving a 65 ppb level. In this case the increase in the magnitude of reduced mortality was more in the range of a 30% to 50% increase. This would be expected since there is greater geography in 2013, 2015, and 2017 that would not have emissions reduced by the BenMap algorithm in the 70 ppb scenario since they were attaining the standard, but they would have been reduced somewhat in the 70 ppb scenario in 2011, 2015, and 2016. The one anomaly is that avoided mortalities increased between the 70 ppb and 65 ppb scenarios in 2012.

In all of the 40 ppb scenarios there is an increase in the modeled avoided mortality from the 65 ppb scenario for the same year, and like the comparison between 65 and 70, the increase depended somewhat on the level of the expanded geography being impacted by the algorithm in addition to the lowering of the ozone levels.

Emergency room visits for asthma related conditions and hospital admissions due to chronic lung disease were estimated not to be significant different than 0.

The same pattern of results occurred for the other health endpoints as mortality with the magnitude being of hospital admissions all respiratory symptoms being about double the mortality incidence and for pneumonia being about half of the mortality incidence. Acute respiratory symptoms were roughly 2000 times the mortality incidence, and school loss days were roughly 500 times.

State level graphs showing the mean mortality for each year from 2011-2018 for having met 70 ppb, 65 ppb, and 40 ppb are in Figure 35, Figure 36, and Figure 37, respectively.

Looking specifically at the 70 ppb scenario, you can see in 2013 and 2014 that states in the far southern OTR (Virginia, Maryland, Delaware) and the far northern OTR (Massachusetts, Rhode Island) did not have the same level of mortalities as in other years as would be expected. New York and Pennsylvania saw marked increases in 2012, which also would be expected given the impact ozone had in the central portions of those states in that year. Those two states also saw drops in 2013, 2014, and 2017, though not to nearly zero due to ozone levels still being high near Philadelphia and New York City. Connecticut saw consistently moderate reduced mortalities in all of the scenarios, which would be expected since the state had consistently higher ozone levels, even in 2013 and 2014 and they were concentrated along the higher populations in the state. 2018 appeared to be an average year across the board.

A full listing of state level breakdowns is available upon request.

Economic Impact

Following analysis of the health impacts, economic impacts were estimated using the previously discussed techniques. The value of the mortalities outweigh the other economic impacts considerably, though one should consider that some economic benefits such as reduced personal suffering may not have been monetized for morbidity due to the data, such as cost of illness estimates, used in developing the cost estimates. Again emergency room visits for asthma related conditions and hospital admissions due to chronic lung disease were found to be not significantly different from zero, as were hospital admissions due to all respiratory conditions and minor restricted activity days. Total economic benefits for the OTR, excluding emergency room visits and minor restricted activity days, are found for each year from 2011-2017 for having met 70 ppb, 65 ppb, and 40 ppb in Figure 38, Figure 39, and Figure 40, respectively. Since the differences in mortality estimates do not vary as much from year to year in the 40 ppb rollback, the economic value calculation is more impacted by inflation than the change in mortality. A full break down of the economic impacts is in Table 5 and state level breakdowns are available upon request.

Summary

Reductions in ozone levels are still necessary to meet the 70 ppb NAAQS. Every year that the OTR is not in attainment of the NAAQS, as this analysis shows, residents of the region die prematurely and face a decreased quality of life due to the health effects of ozone. These health effects come with an economic price tag as well. Lowering the NAAQS at a future date, and then meeting a lower NAAQS would bring even more health benefits than simply meeting the current 70 ppb NAAQS as well.

Figure 35: Estimated state mortalities that could have been avoided by meeting a 70 ppb threshold from 2011-2018

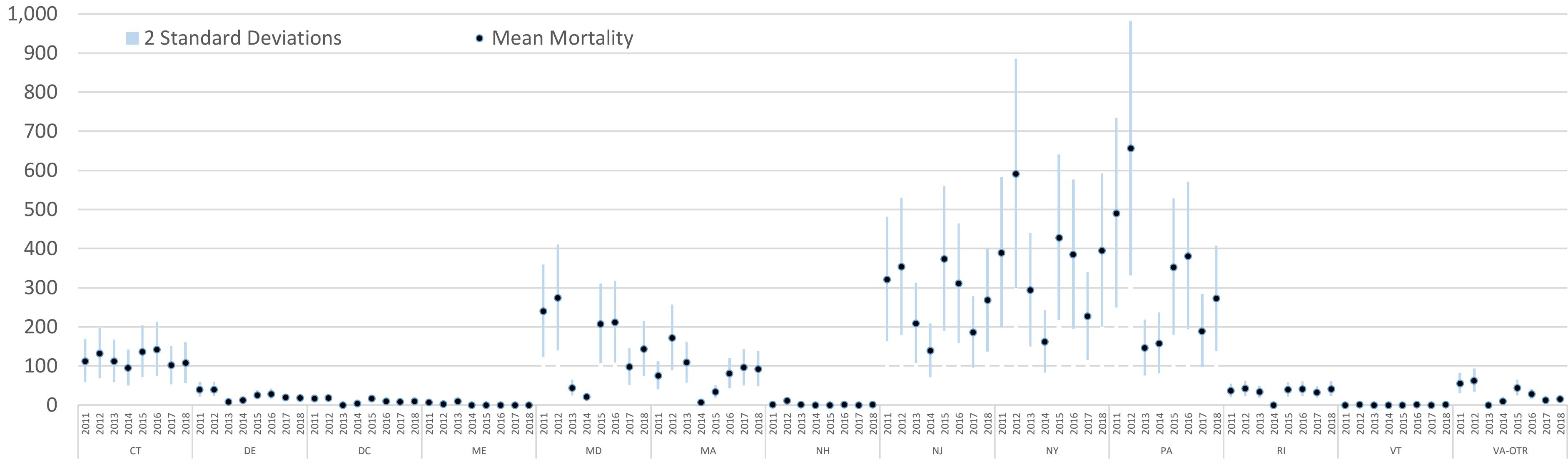


Figure 36: Estimated state mortalities that could have been avoided by meeting a 65 ppb threshold from 2011-2018

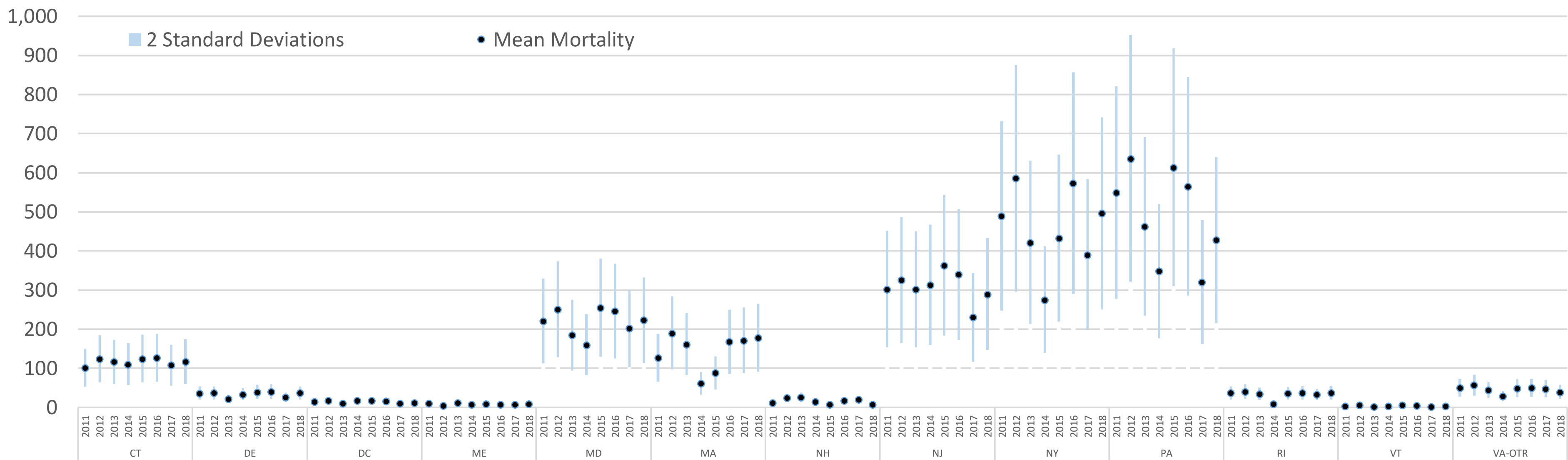


Figure 37: Estimated state mortalities that could have been avoided by meeting a 40 ppb threshold from 2011-2018

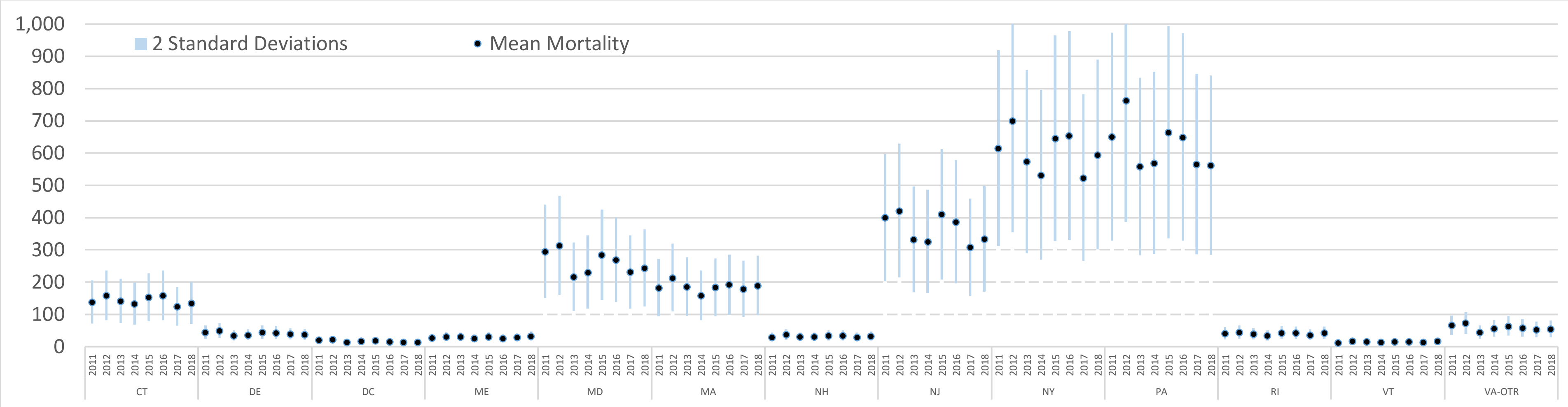


Figure 38: Estimated state level economic benefits that could have occurred by meeting a 70 threshold NAAQS from 2011-2018

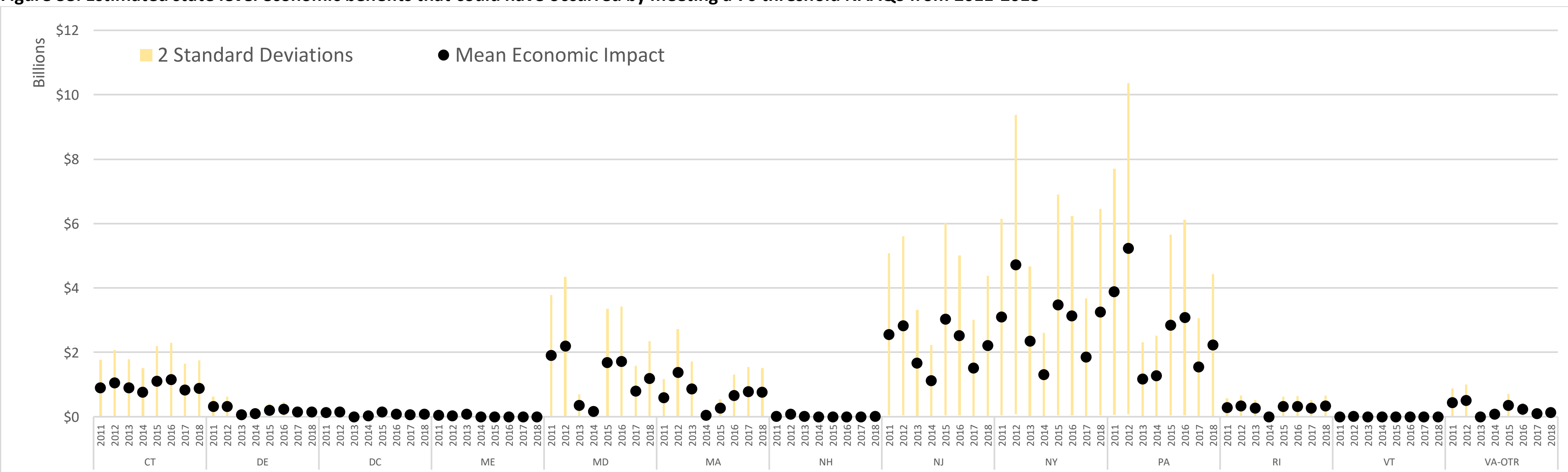


Figure 39: Estimated state level economic benefits that could have occurred by meeting a 65 ppb threshold from 2011-2018

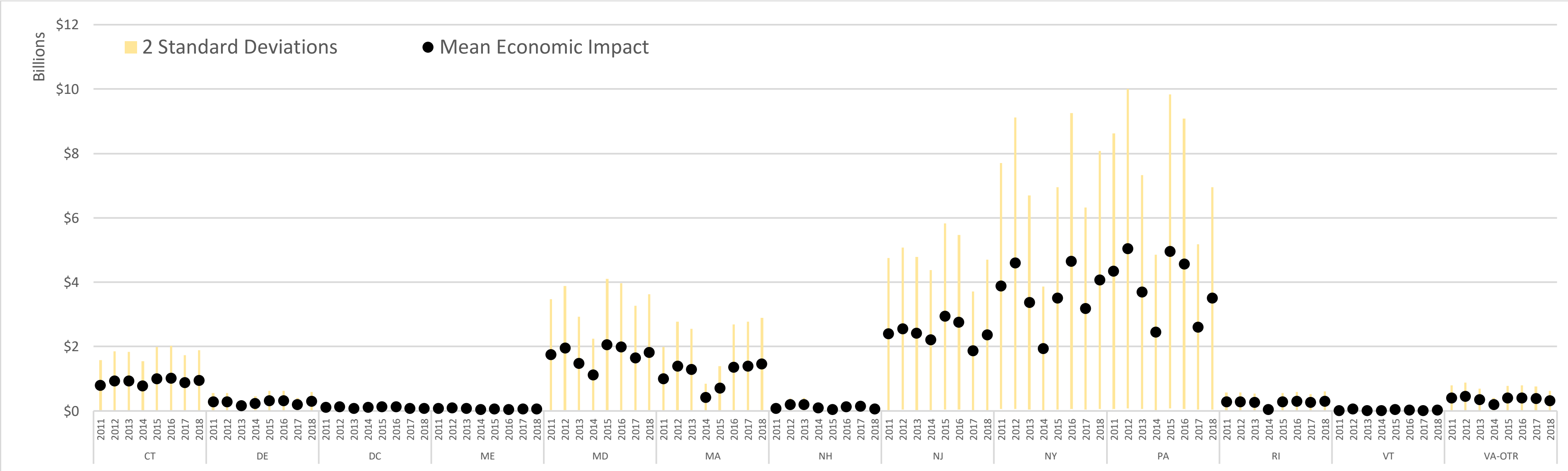


Figure 40: Estimated state level economic benefits that could have occurred by meeting a 40 ppb threshold from 2011-2018

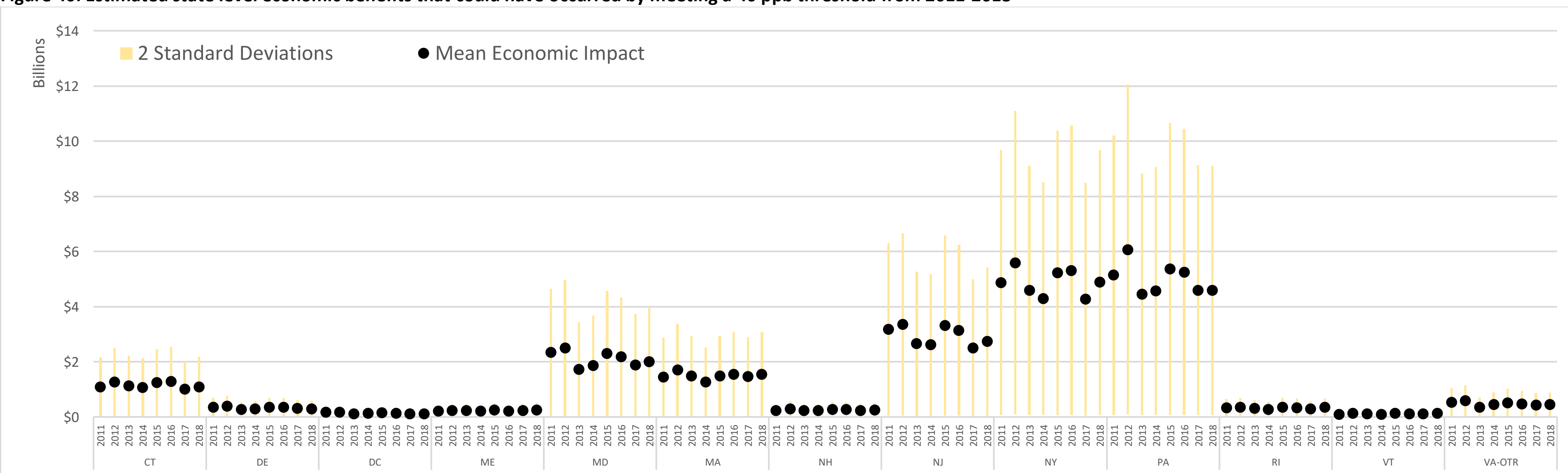


Table 4: Estimated ozone-related health impacts following monitor rollback to 40, 65, and 70 ppb for 2011-2018 in the OTR

	2011			2012			2013			2014			2015			2016			2017			2018		
	40	65	70	40	65	70	40	65	70	40	65	70	40	65	70	40	65	70	40	65	70	40	65	70
Mortality																								
All Causes[7]																								
Mean	2,512	1,941	1,782	2,833	2,288	2,355	2,204	1,790	963	2,152	1,370	606	2,584	2,030	1,656	2,535	2,180	1,617	2,136	1,559	967	2,279	1,866	1,363
-2σ	1,264	975	896	1,426	1,150	1,184	1,107	899	483	1,081	688	304	1,299	1,020	832	1,275	1,095	812	1,073	783	485	1,146	937	684
2σ	3,760	2,907	2,668	4,240	3,425	3,525	3,301	2,682	1,442	3,224	2,052	908	3,869	3,040	2,480	3,796	3,265	2,422	3,199	2,335	1,449	3,412	2,795	2,041
E.R. Visits																								
Asthma[8]																								
Mean	2,789	2,149	2,112	3,028	2,472	2,599	2,323	1,937	1,052	2,281	1,581	817	2,700	2,166	1,934	2,611	2,313	1,743	2,151	1,708	1,065	2,303	1,937	1,589
-2σ	-551	-429	-420	-597	-492	-516	-464	-389	-212	-456	-317	-165	-536	-432	-385	-519	-462	-349	-430	-342	-215	-458	-387	-317
2σ	6,129	4,727	4,643	6,653	5,436	5,713	5,110	4,264	2,315	5,018	3,479	1,799	5,936	4,764	4,252	5,740	5,088	3,836	4,731	3,759	2,344	5,064	4,262	3,495
Hospital Admissions																								
All Respiratory[9]																								
Mean	5,003	3,873	3,630	5,592	4,535	4,677	4,383	3,614	1,972	4,317	2,809	1,300	5,182	4,070	3,403	5,118	4,392	3,309	4,326	3,270	2,048	4,646	3,844	2,858
-2σ	1,082	847	795	1,192	940	936	858	765	413	857	586	317	1,048	830	746	1,034	874	693	833	685	425	885	776	632
2σ	8,924	6,900	6,465	9,993	8,130	8,419	7,909	6,464	3,531	7,778	5,032	2,283	9,317	7,310	6,061	9,201	7,911	5,925	7,819	5,855	3,672	8,406	6,912	5,084
Chronic Lung Disease[10]																								
Mean	1,112	860	803	1,258	1,020	1,050	996	816	445	982	632	284	1,182	931	762	1,169	1,006	754	998	737	465	1,072	882	647
-2σ	-189	-149	-138	-213	-176	-180	-172	-143	-78	-170	-111	-50	-203	-161	-132	-201	-174	-131	-173	-129	-82	-184	-153	-112
2σ	2,413	1,870	1,745	2,729	2,216	2,280	2,164	1,775	969	2,134	1,375	618	2,567	2,024	1,656	2,540	2,186	1,640	2,169	1,602	1,011	2,329	1,917	1,406
Pneumonia[11]																								
Mean	1,481	1,140	1,042	1,679	1,358	1,387	1,328	1,078	581	1,299	810	353	1,558	1,202	967	1,539	1,309	970	1,313	961	594	1,408	1,152	816
-2σ	646	494	452	733	589	603	575	465	250	562	349	152	677	520	419	668	567	419	568	414	256	611	498	353
2σ	2,317	1,787	1,631	2,624	2,126	2,171	2,080	1,691	913	2,037	1,271	555	2,439	1,884	1,515	2,409	2,052	1,520	2,057	1,507	933	2,206	1,805	1,280
Acute Respiratory Symptoms																								
Minor Restricted Activity Days[12]																								
Mean	5,027,417	3,853,844	3,656,790	5,499,157	4,452,611	4,616,240	4,224,944	3,487,051	1,863,796	4,119,931	2,696,398	1,252,907	4,854,579	3,795,748	3,262,483	4,693,320	4,074,157	3,057,706	3,889,980	3,002,829	1,850,554	4,106,161	3,412,837	2,592,454
-2σ	2,282,001	1,737,202	1,652,272	2,500,062	2,011,921	2,090,287	1,904,364	1,567,359	834,756	1,856,045	1,211,031	560,351	2,196,533	1,711,570	1,472,641	2,122,249	1,837,475	1,376,737	1,753,234	1,350,122	829,636	1,856,055	1,538,225	1,168,925
2σ	7,772,834	5,970,487	5,661,308	8,498,252	6,893,301	7,142,194	6,545,524	5,406,742	2,892,835	6,383,817	4,181,766	1,945,464	7,512,625	5,879,926	5,052,326	7,264,392	6,310,839	4,738,674	6,026,725	4,655,537	2,871,472	6,356,267	5,287,449	4,015,982
School Loss Days																								
All Causes[13]																								
Mean	1,499,207	1,122,772	1,068,105	1,632,181	1,290,416	1,340,668	1,208,487	1,001,060	526,715	1,170,208	762,783	350,565	1,368,612	1,072,447	917,599	1,316,262	1,139,641	859,887	1,082,564	833,056	510,905	1,141,935	946,712	714,887
-2σ	521,060	453,909	431,775	567,519	521,631	541,894	488,541	404,747	212,995	473,113	308,449	141,795	553,231	433,600	370,983	532,062	460,742	347,680	437,657	336,834	206,614	461,621	382,765	289,051
2σ	2,477,355	1,791,634	1,704,435	2,696,842	2,059,201	2,139,441	1,928,432	1,597,373	840,436	1,867,302	1,217,118	559,334	2,183,993	1,711,294	1,464,215	2,100,462	1,818,541	1,372,094	1,727,471	1,329,278	815,196	1,822,249	1,510,659	1,140,722

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[7] Bell, Dominici, and Samet, "A Meta-Analysis of Time-Series Studies of Ozone and Mortality With Comparison to the National Morbidity, Mortality, and Air Pollution Study."
[8] Wilson et al., "Air Pollution, Weather, and Respiratory Emergency Room Visits in Two Northern New England Cities: An Ecological Time-Series Study"; Peel et al., "Ambient Air Pollution and Respiratory Emergency Department Visits."
[9] Burnett et al., "Association between Ozone and Hospitalization for Acute Respiratory Diseases in Children Less than 2 Years of Age"; Schwartz, "Short Term Fluctuations in Air Pollution and Hospital Admissions of the Elderly for Respiratory Disease."
[10] Moolgavkar, Luebeck, and Anderson, "Air Pollution and Hospital Admissions for Respiratory Causes in Minneapolis-St. Paul and Birmingham."
[11] Ibid.; Schwartz, "Air Pollution and Hospital Admissions for the Elderly in Detroit, Michigan."; Schwartz, "PM10 Ozone, and Hospital Admissions for the Elderly in Minneapolis-St. Paul, Minnesota."
[12] Ostro and Rothschild, "Air Pollution and Acute Respiratory Morbidity: An Observational Study of Multiple Pollutants."
[13] Chen et al., "Elementary School Absenteeism and Air Pollution"; Gilliland et al., "The Effects of Ambient Air Pollution on School Absenteeism Due to Respiratory Illnesses."

Table 5: Estimated ozone-related economic impacts (2010$) following monitor rollback to 70, 65, and 40 ppb for 2011-2018 in the OTR

	2011			2012			2013			2014			2015			2016			2017			2018		
	40	65	70	40	65	70	40	40	65	70	65	70	40	65	70	40	65	70	40	65	70	40	65	70
Mortality																								
All Causes																								
Mean	$19,641	$15,177	$13,932	$22,277	$17,698	$18,517	$17,393	$14,126	$7,596	$17,099	$9,525	$4,809	$20,660	$16,228	$13,241	$20,319	$17,473	$12,958	$17,214	$12,562	$7,791	$18,455	$15,112	$11,034
-2σ	$298	$224	$207	$341	$263	$2789	$257	$206	$109	$251	$138	$68	$310	$240	$196	$304	$258	$190	$254	$183	$112	$275	$223	$163
2σ	$38,984	$30,130	$27,658	$44,212	$35,132	$36,755	$34,530	$28,046	$15,083	$33,930	$18,912	$9,549	$41,010	$32,217	$26,286	$40,334	$34,689	$25,726	$34,174	$24,942	$15,470	$36,634	$30,002	$21,905
Emergency Room Visits																								
Asthma																								
Mean	$1.1	$0.8	$0.8	$1.2	$0.9	$1.0	$0.9	$0.8	$0.4	$0.9	$0.6	$0.3	$1.0	$0.8	$0.8	$1.0	$0.9	$0.7	$0.8	$0.7	$0.4	$0.9	$0.8	$0.6
-2σ	-$0.2	-$0.2	-$0.2	-$0.2	-$0.2	-$0.2	-$0.2	-$0.2	-$0.1	-$0.2	-$0.1	-$0.1	-$0.2	-$0.2	-$0.1	-$0.2	-$0.2	-$0.1	-$0.2	-$0.1	-$0.1	-$0.2	-$0.2	-$0.1
2σ	$2.4	$1.8	$1.8	$2.6	$2.1	$2.2	$2.0	$1.7	$0.9	$1.9	$1.4	$0.7	$2.3	$1.8	$1.7	$2.2	$2.0	$1.5	$1.8	$1.5	$0.9	$2.0	$1.7	$1.4
Hospital Admissions																								
All Respiratory																								
Mean	$153.2	$118.9	$111.3	$171.5	$138.0	$143.5	$136.0	$111.9	$60.6	$133.8	$86.1	$39.1	$160.9	$126.2	$104.2	$159.2	$136.4	$101.8	$135.6	$100.6	$63.4	$145.2	$119.4	$88.2
-2σ	-$14.7	-$12.0	-$9.8	-$16.8	-$13.9	-$14.0	-$15.5	-$12.7	-$6.7	-$14.6	-$8.8	-$3.3	-$16.4	-$13.4	-$9.4	-$16.6	-$15.3	-$11.1	-$15.5	-$10.5	-$7.2	-$16.4	-$13.4	-$7.7
2σ	$321.2	$249.7	$232.3	$359.7	$290.0	$301.1	$287.5	$236.5	$127.9	$282.2	$181.0	$81.5	$338.2	$265.9	$217.9	$335.0	$288.1	$214.7	$286.7	$211.7	$134.0	$306.7	$252.2	$184.0
Chronic Lung Disease																								
Mean	$25.5	$19.7	$18.4	$28.8	$23.0	$24.0	$22.8	$18.7	$10.2	$22.5	$14.5	$6.5	$27.1	$21.3	$17.5	$26.8	$23.0	$17.3	$22.8	$16.9	$10.6	$24.6	$20.2	$14.8
-2σ	-$4.3	-$3.4	-$3.2	-$4.9	-$4.0	-$4.1	-$3.9	-$3.3	-$1.8	-$3.9	-$2.5	-$1.2	-$4.6	-$3.7	-$3.0	-$4.6	-$4.0	-$3.0	-$4.0	-$2.9	-$1.9	-$4.2	-$3.5	-$2.6
2σ	$55.3	$42.8	$40.0	$62.5	$49.9	$52.2	$49.5	$40.7	$22.2	$48.9	$31.5	$14.2	$58.8	$46.3	$37.9	$58.2	$50.1	$37.6	$49.7	$36.7	$23.2	$53.3	$43.9	$32.2
Pneumonia																								
Mean	$40.4	$31.1	$28.4	$45.7	$36.4	$37.8	$36.2	$29.4	$15.9	$35.4	$22.1	$9.6	$42.5	$32.8	$26.4	$41.9	$35.7	$26.4	$35.8	$26.2	$16.2	$38.4	$31.4	$22.3
-2σ	$17.6	$13.5	$12.3	$20.0	$15.8	$16.4	$15.7	$12.7	$6.8	$15.3	$9.5	$4.1	$18.5	$14.2	$11.4	$18.2	$15.5	$11.4	$15.5	$11.3	$7.0	$16.7	$13.6	$9.6
2σ	$63.1	$48.7	$44.5	$71.5	$57.0	$59.2	$56.7	$46.1	$24.9	$55.5	$34.7	$15.1	$66.5	$51.3	$41.3	$65.7	$55.9	$41.4	$56.1	$41.1	$25.4	$60.1	$49.2	$34.9
Acute Respiratory Symptoms																								
Minor Restricted Activity Days																								
Mean	$160.2	$122.8	$116.6	$175.6	$140.0	$147.4	$135.1	$111.5	$59.6	$132.1	$82.3	$40.2	$156.0	$122.0	$104.9	$151.0	$131.1	$98.4	$125.4	$96.8	$59.7	$132.6	$110.2	$83.7
-2σ	-$50.7	-$39.1	-$37.0	-$55.5	-$44.5	-$46.7	-$43.0	-$35.6	-$19.1	-$42.0	-$26.2	-$12.9	-$49.5	-$38.8	-$33.3	-$47.9	-$41.7	-$31.3	-$39.9	-$30.9	-$19.1	-$42.1	-$35.1	-$26.6
2σ	$371.1	$284.8	$270.1	$406.7	$324.5	$341.6	$313.3	$258.7	$138.3	$306.2	$190.8	$93.2	$361.5	$282.8	$243.0	$349.8	$303.8	$228.1	$290.7	$224.5	$138.4	$307.3	$255.5	$194.1
School Loss Days																								
All Causes																								
Mean	$143.9	$107.8	$102.5	$156.7	$121.9	$128.7	$116.0	$96.1	$50.6	$112.3	$73.2	$33.6	$131.4	$102.9	$88.1	$126.3	$109.4	$82.5	$103.9	$80.0	$49.0	$109.6	$90.9	$68.6
-2σ	$50.2	$43.8	$41.6	$54.6	$49.5	$52.3	$47.1	$39.0	$20.5	$45.6	$29.7	$13.7	$53.4	$41.8	$35.8	$51.3	$44.4	$33.5	$42.2	$32.5	$19.9	$44.5	$36.9	$27.9
2σ	$237.6	$171.7	$163.4	$258.7	$194.3	$205.1	$184.9	$153.1	$80.6	$179.0	$116.7	$53.6	$209.4	$164.0	$140.4	$201.3	$174.3	$131.5	$165.6	$127.4	$78.2	$174.7	$144.8	$109.4

Table 6: Top causes of death according to 2014 CDC data for the OTR and all of Virginia

Health Endpoint	Rank	Mortalities	Health Endpoint	Rank	Mortalities
Coronary Heart Disease	1	91,148	Homicide	33	2,599
Lung Cancers	2	34,976	Stomach Cancer	34	2,592
Stroke	3	27,908	Diarrhoeal diseases	35	2,442
Lung Disease	4	27,039	Oral Cancer	36	1,763
Diabetes Mellitus	5	16,138	HIV/AIDS	37	1,547
Hypertension	6	15,474	Alcohol	38	1,492
Alzheimer’s	7	15,175	Congenital Anomalies	39	1,440
Influenza & Pneumonia	8	13,774	Hepatitis C	40	1,266
Colon-Rectum Cancers	9	12,017	Low Birth Weight	41	1,077
Kidney Disease	10	11,559	Skin Disease	42	995
Blood Poisoning	11	10,816	Multiple Sclerosis	43	798
Breast Cancer	12	9,842	Asthma	44	728
Pancreas Cancer	13	9,823	Cervical Cancer	45	722
Poisoning	14	9,748	Anaemia	46	652
Endocrine Disorders	15	9,176	Rheumatic/Heart	47	617
Lymphomas	16	7,882	Malnutrition	48	404
Suicide	17	7,779	Drug Use	49	293
Inflammatory/Heart	18	7,233	Peptic Ulcer Disease	50	273
Falls	19	6,799	Birth Trauma	51	218
Liver Disease	20	6,632	Rheumatoid Arthritis	52	208
Prostate Cancer	21	6,522	Fires	53	135
Parkinson's Disease	22	5,811	Drownings	54	68
Liver Cancer	23	5,304	Diphtheria	55	-
Road Traffic Accidents	24	5,197	Measles	55	-
Leukemia	25	5,173	Osteoarthritis	55	-
Other Injuries	26	4,753	Meningitis	55	-
Bladder Cancer	27	4,010	Oral conditions	55	-
Other Neoplasms	28	3,698	Pertussis	55	-
Oesophagus Cancer	29	3,608	Tetanus	55	-
Ovary Cancer	30	3,319	Prostatic Hypertrophy	55	-
Skin Cancers	31	2,720	War	55	-
Uterine Cancer	32	2,609	Appendicitis	55	-