Analysis of the Potential Health Impacts of Reducing Ozone Levels in the OTR Using BenMAP – 2020 Edition

Includes data through 2019

Ozone Transport Commission
OTC Modeling Committee
September 16, 2020

OZONE
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COMMISSION

Executive Summary

This analysis estimates potential health benefits from "rolling back" observed ozone levels in the Ozone Transport Region (OTR) to three alternative ozone levels: 70 ppb, 65 ppb, and 40 ppb. These levels were selected in light of the following considerations. First, in 2015, the 8-hour ozone National Ambient Air Quality Standard (NAAQS) was lowered to 70 ppb. This was at the high end of the range recommended by the Clean Air Scientific Advisory Committee (CASAC) originally and in the EPA rule proposal. Second, the lower end of the range originally proposed by EPA was 65 ppb. Third, recent research has shown health effects from ozone occur at even lower levels with no known threshold for no effects. Therefore, given that health effects could be caused at levels closer to what is considered background, this analysis looked at 40 ppb, which close to a level considered to be United States Background (USB).

Each year, exposure to elevated ozone affects the health of millions of people in the OTR. The Ozone Transport Commission (OTC) began examining the potential health impacts of these levels of exposure starting in 2011 and up to 2019, the most recent year for which data was available at the time of this latest analysis. This report will focus on each ozone season for which data has been processed, 2011-2019, with the intention of adding new information annually.

Several states in the OTR exceed the ozone NAAQS set by EPA, which is intended to protect public health with an adequate margin of safety. This indicates 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 2011-2019, 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 during 2011-2019 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 benefits to the region in the range of $5-19 billion in all health impacts from reducing ozone to 70 ppb in any given year.

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Introduction

This analysis estimates potential health benefits from "rolling back" observed ozone levels in the Ozone Transport Region (OTR) to three alternative ozone levels: 70 ppb, 65 ppb, and 40 ppb. These levels were selected in light of the following considerations. First, in 2015, the 8-hour ozone National Ambient Air Quality Standard (NAAQS) was lowered to 70 ppb. This was at the high end of the range recommended by the Clean Air Scientific Advisory Committee (CASAC) originally and in the EPA rule proposal. Second, the lower end of the range originally proposed by EPA was 65 ppb. Third, recent research has shown health effects from ozone occur at even lower levels with no known threshold for no effects. Therefore, given that health effects could be caused at levels closer to what is considered background, this analysis looked at 40 ppb, which close to a level considered to be United States Background (USB).

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Several states in the OTR exceed the ozone NAAQS set by EPA, which is intended to protect public health with an adequate margin of safety. This indicates 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 2011-2019 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.[1]

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.

Change in Air Quality

[1] US EPA, *Environmental Benefits Mapping and Analysis Program – Community Edition: User's Manual* (2018).

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 2011-2019 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.[2] 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, which limits this effect.

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; 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 certain thresholds be met in order for 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, Therefore, the time span of May 1 – September 30 was used, with a requirement for 50% valid days. The default start and end hours were also used. Because exceedances do occur outside of the May to September window but within the ozone monitoring season in Table 1, there are a few cases when an exceeding monitor will not be rolled back. These cases will be when there are four or more exceedances during the full ozone season, but fewer than four exceedances between May 1 and September 30.

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

The 4th high 8-hour ozone data for each year can be seen in Figure 1 though Figure 9, and data for the 19 worst monitors in the OTR based on 2019 4th highest values can be seen in Table 2.

[2] Ozone Transport Commission, *Technical Support Document for the 2011 Ozone Transport Commission/Mid-Atlantic Northeastern Visibility Union Modeling Platform* (2016).

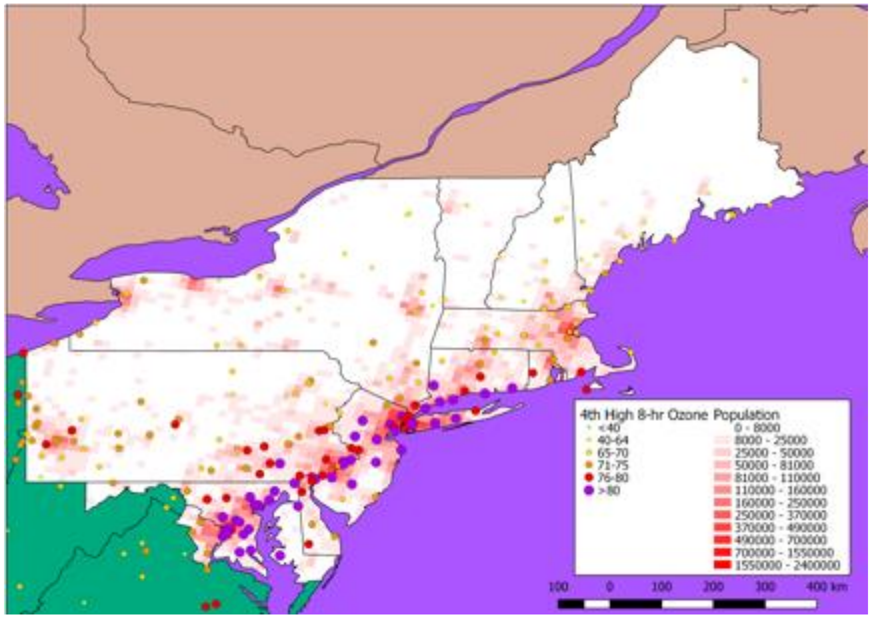


Figure 1: 4th high monitored 8-hour ozone values and gridded population for 2011

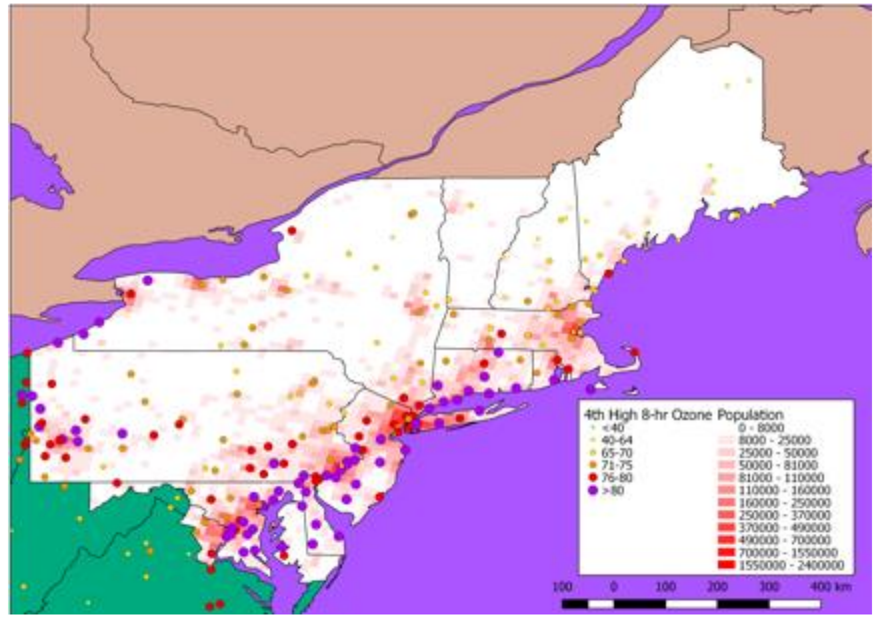


Figure 2: 4th high monitored 8-hour ozone values and gridded population for 2012

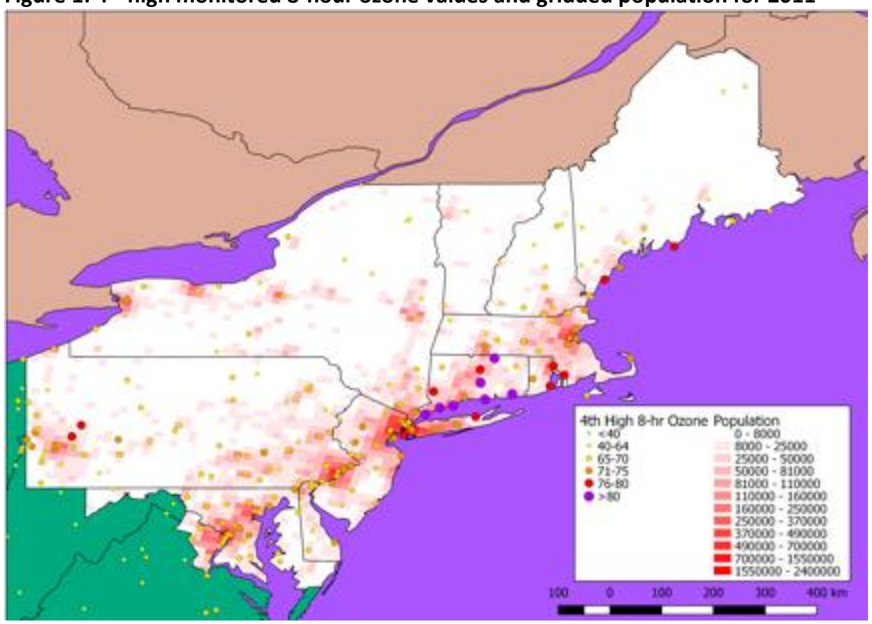


Figure 3: 4th high monitored 8-hour ozone values and gridded population for 2013

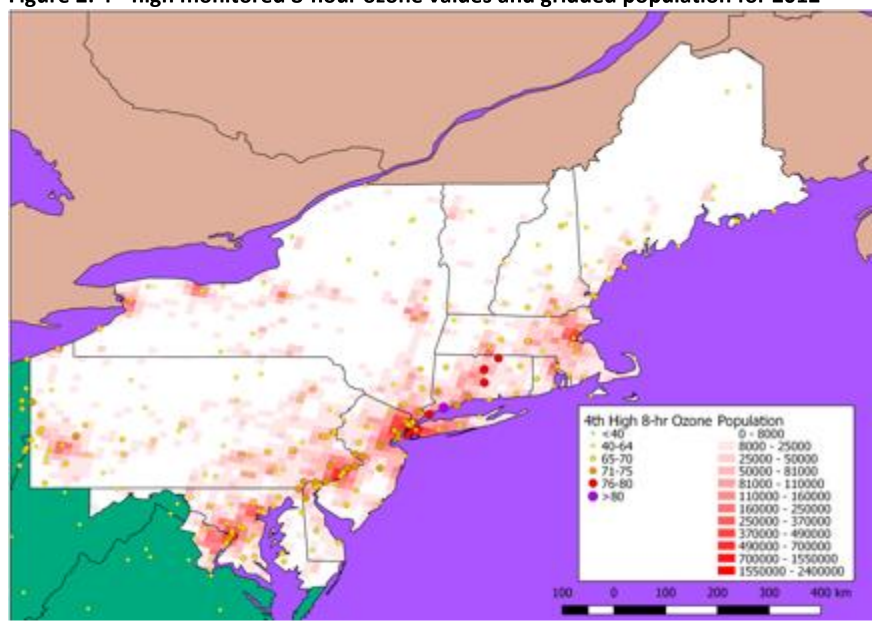


Figure 4: 4th high monitored 8-hour ozone values and gridded population for 2014

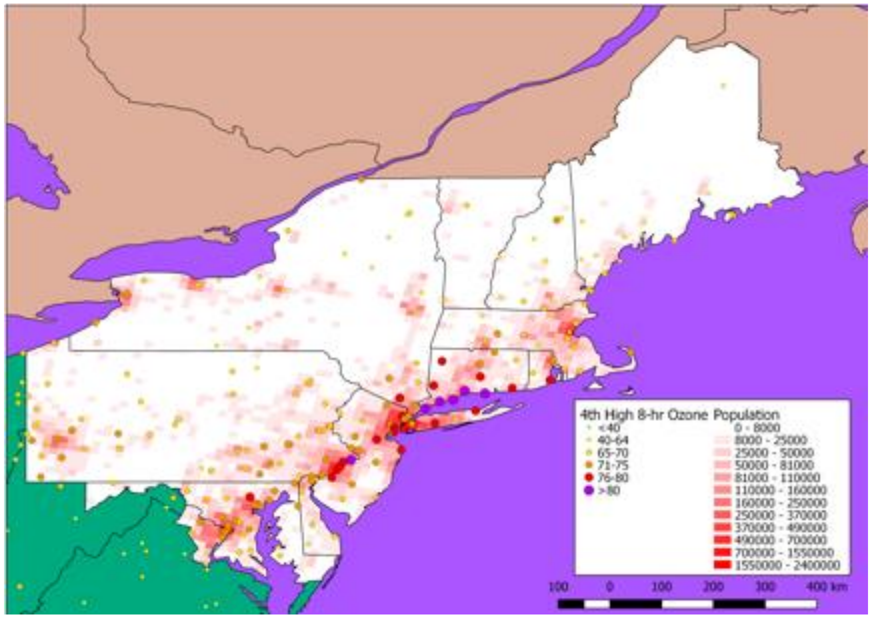


Figure 5: 4th high monitored 8-hour ozone values and gridded population for 2015

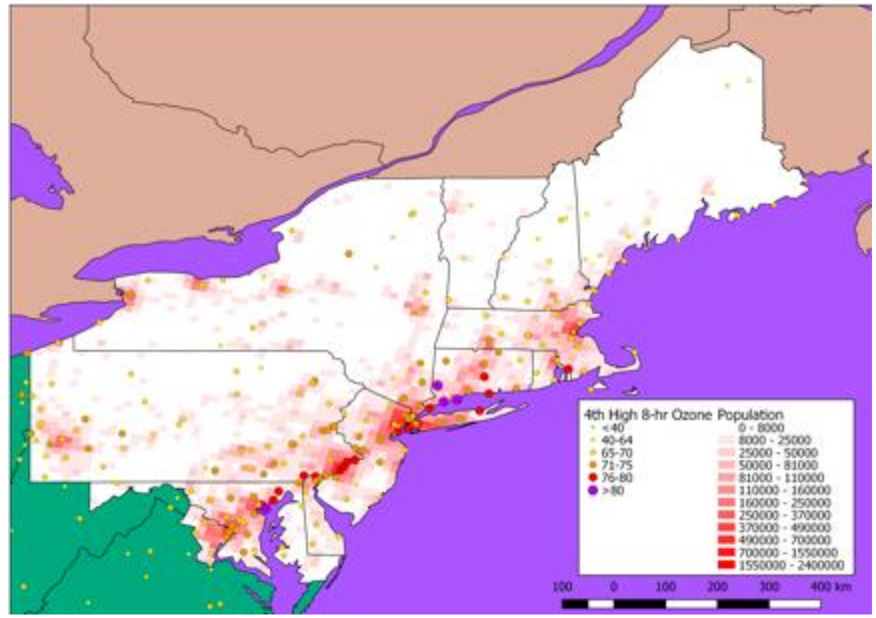


Figure 6: 4th high monitored 8-hour ozone values and gridded population for 2016

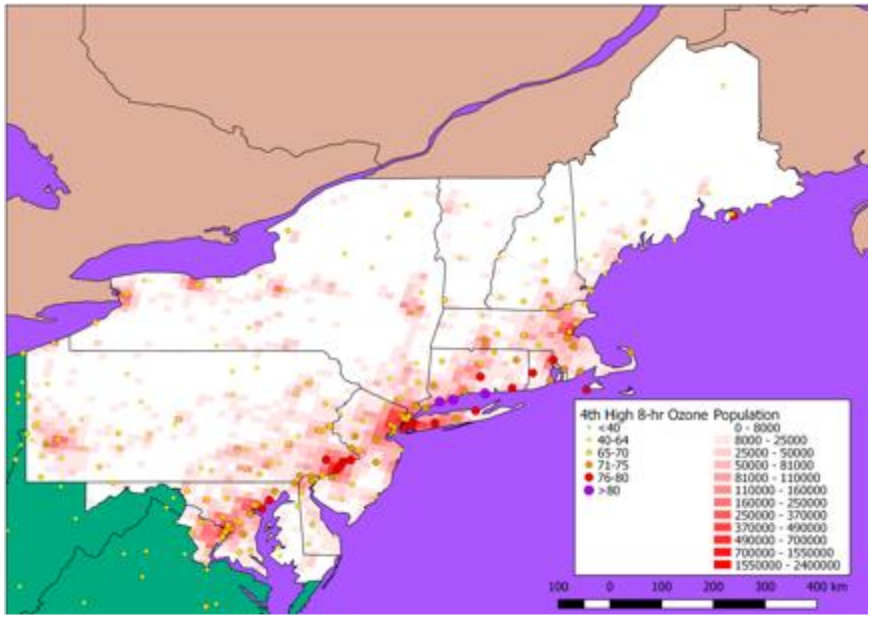


Figure 7: 4th high monitored 8-hour ozone values and gridded population for 2017

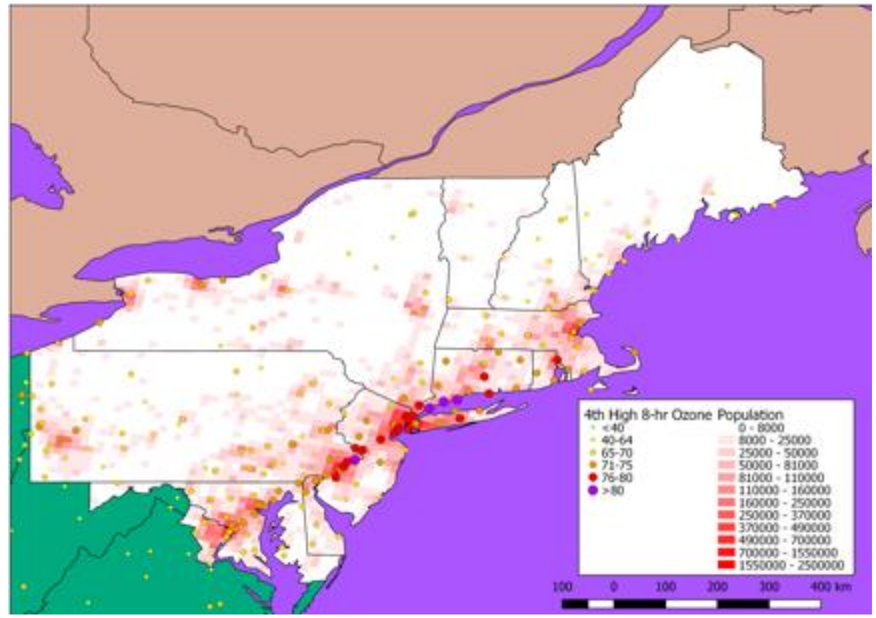


Figure 8: 4th high monitored 8-hour ozone values and gridded population for 2018

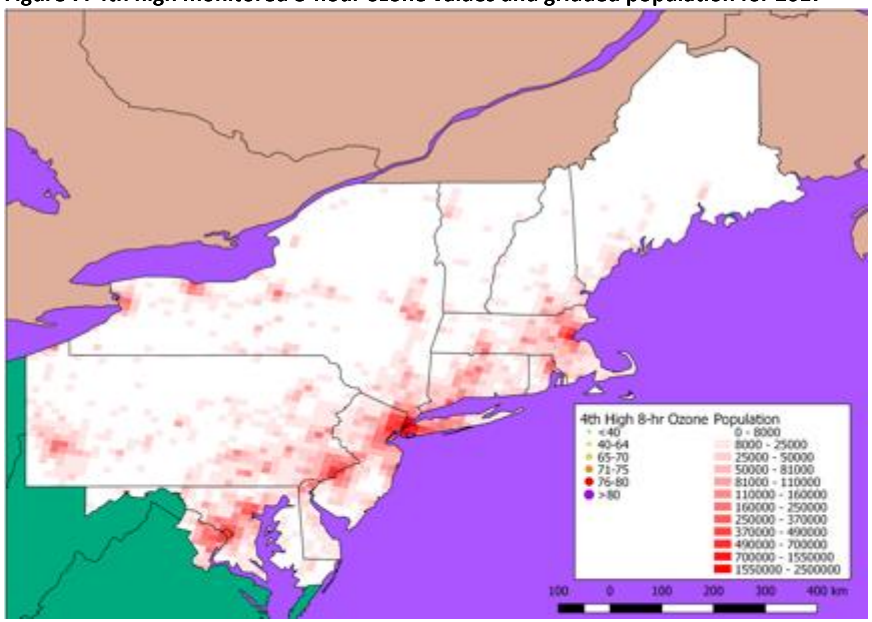


Figure 9: 4th high monitored 8-hour ozone values and gridded population for 2019

Table 2: 4th highest 8-hour ozone concentrations from 2011 – 2019 (ordered by 2019 concentrations)

	State	Site Name	AQS Code	4th Highest 8-hr Ozone Concentrations								
				2011	2012	2013	2014	2015	2016	2017	2018	2019
1	CT	Greenwich	90010017	81	88	82	78	84	79	74	86	84
2	CT	Madison-combined	90099002	92	90	85	69	81	80	86	77	84
3	CT	Stratford	90013007	87	90	90	74	86	83	81	83	82
4	CT	Westport	90019003	87	89	86	81	87	81	81	84	81
5	CT	New Haven-B	90090027	80	81	75	72	81	75	75	72	78
6	MD	Edgewood	240251001	98	86	72	67	74	77	76	74	77
7	CT	Middletown-combined	90079007	80	81	82	80	78	80	79	77	76
8	MD	Furley E.S. Rec Center	245100054	82	71	63	60	72	67	69	74	76
9	MD	Glen Burnie	240031003						74	73	75	76
10	CT	Groton Fort Griswold	90110124	82	87	85	65	77	75	78	74	75
11	MD	Beltsville	240339991	84	84	72	69	67	70	70	73	75
12	MD	Essex	240053001	85	83	67	68	72	78	71	71	74
13	CT	Stafford	90131001	68	83	81	77	72	72	70	71	73
14	NY	Flax Pond	361030044								74	73
15	CT	Danbury	90011123	83	84	76	74	79	81	72	75	72
16	CT	East Hartford	90031003	74	77	77	77	75	72	70	67	72
17	NY	Babylon	361030002	89	83	72	66	78	73	77	74	72
18	PA	NEW	421010048				68	78	76	76	76	72
19	DC	McMillan	110010043	85	87	66	68	72	72	71	73	71
20	MA	Martha's Vineyard	250070001	78	82	65	59		66	76	68	71
21	MD	HU-Beltsville	240330030	83	79	68	65	72	70	69	70	71
22	NJ	Leonia	340030006	82	76	74	73	76	73	74	79	71
23	NY	NYC-Queens	360810124	84	82	71	63	73	71	79	73	71
24	PA	NEA	421010024	89	85	68	72	79	80	76	79	71

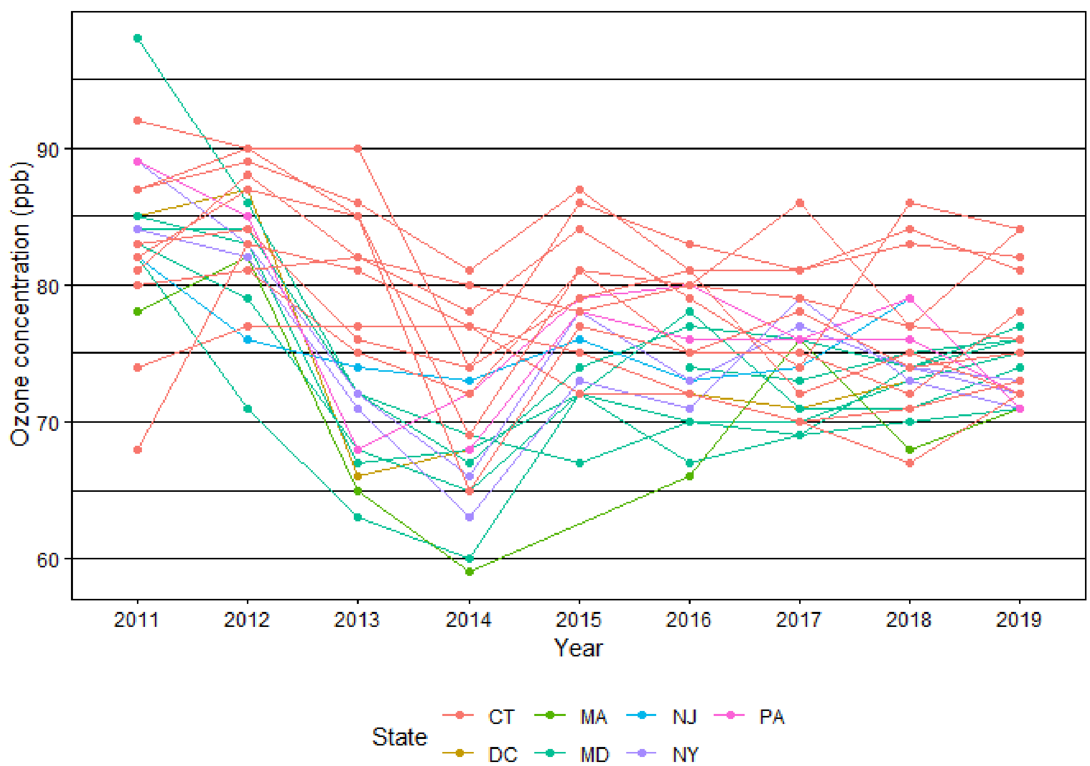


Figure 10: 4th highest 8-hour ozone concentrations (ppb) from 2011 – 2019 for monitors with 2019 concentration > 70ppb

Table 3: Design values from 2011 – 2019 (ordered by 2017-19 concentrations)

	State	Site Name	AQS Code	Design Values						
				2011-13	2012-14	2013-15	2014-16	2015-17	2016-18	2017-19
1	CT	Madison-combined	90099002	89	81	78	76	82	81	82
2	CT	Stratford	90013007	89	84	83	81	83	82	82
3	CT	Westport	90019003	87	85	84	83	83	82	82
4	CT	Greenwich	90010017	83	82	81	80	79	79	81
5	CT	Middletown-combined	90079007	81	81	80	79	79	78	77
6	PA	Bristol	420170012	78	75	75	77	80	81	76
7	CT	Groton Fort Griswold	90110124	84	79	75	72	76	75	75
8	CT	New Haven-B	90090027	78	76	76	76	77	74	75
9	MD	Edgewood	240251001	85	75	71	72	75	75	75
10	PA	NEA	421010024	80	75	73	77	78	78	75
11	MD	Glen Burnie	240031003						74	74
12	NJ	Leonia	340030006	77	74	74	74	74	75	74
13	NY	Babylon	361030002	81	73	72	72	76	74	74
14	NY	NYC-Queens	360810124	79	72	69	69	74	74	74
15	PA	NEW	421010048				74	76	76	74
16	CT	Danbury	90011123	81	78	76	78	77	76	73
17	MD	Furley E.S. Rec Center	245100054	72	64		66	69	70	73
18	NJ	Camden-Spruce St	340070002		73	70	74	77	75	73
19	NJ	Rutgers U	340230011	79	74	72	74	75	75	73
20	NY	White Plains	361192004	75	75	73	74	73	75	73
21	RI	E Providence	440071010	76	73	70	66	70	73	73
22	MD	Beltsville	240339991	80	75	69	68	69	71	72
23	MD	Essex	240053001	78	72	69	72	73	73	72
24	MD	Fair Hill	240150003	82	77	73	74	74	74	72
25	NJ	Clarksboro	340150002	84	76	73	73	74	74	72
26	NJ	Colliers Mills	340290006	80	75	72	72	73	73	72
27	NJ	Wash Crossing	340219991	76	73	71	73	73	74	72
28	NY	Riverhead	361030004	80	75	72	72	76	75	72
29	CT	Abington	90159991	71	70	68	68	70	71	71
30	CT	Stafford	90131001	77	80	76	73	71	71	71
31	DC	McMillan	110010043	79	73	68	70	71	72	71
32	MA	Martha's Vineyard	250070001	75	68				70	71
33	NY	NYBG-Bronx-combined	360050133	74	71	70	70	70	72	71
34	NY	NYC-CCNY	360610135	72	67	66	69	70	72	71

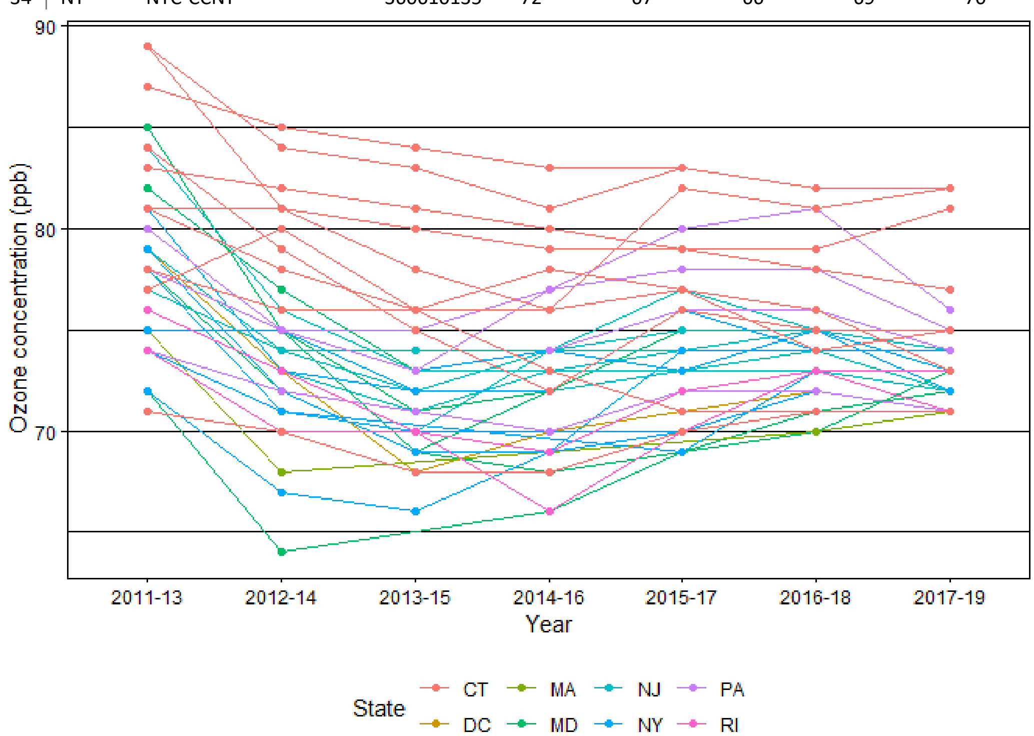


Figure 11: Ozone DV concentrations (ppb) from 2011-13 – 2017-19 for monitors with 2017-19 DV > 70ppb

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). BenMAP CE, however, only accepts one year's 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 can 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, setting an ozone background level was necessary to prevent monitors from being lowered below what would occur absent anthropogenic emissions. There are a variety of estimates for 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.[3] This is the value presented in Figure 3-9 of EPA's Integrated Scientific Assessment for the 2015 Ozone NAAQS. 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.

One potential drawback with the rollback approach is that only monitors that have 4th highest values above 70 ppb were rolled back to the standard. In reality, where regional controls are adopted, additional areas would also have reduced ozone concentrations even though their monitors are already below the standard. As a result, the BenMAP-estimated health benefits, in New England in particular, are lower than what would be experienced in a real world scenario.

Population

Table 4: Population for each age cohort by year analyzed (millions people)

	Ages	2011	2012	2013	2014	2015	2016	2017	2018	2019
Mortality										
Mortality, All Cause	*All*	65.8	66.1	66.4	66.6	66.9	67.3	67.7	68.1	68.4
Emergency Room Visits										
Asthma	*All*	65.8	66.1	66.4	66.6	66.9	67.3	67.7	68.1	68.4
Hospital Admissions										
All Respiratory	*0-1*	**5.3**	**5.5**	**5.6**	**5.8**	**5.9**	**6.1**	**6.2**	**6.4**	**13.1**
Chronic Lung Disease	*65+*	9.1	9.5	9.7	10.0	10.3	10.5	10.8	11.1	11.4
Pneumonia	*65+*	9.1	9.5	9.7	10.0	10.3	10.5	10.8	11.1	11.4
Acute Respiratory Symptoms										
Minor Restricted Activity Days	*18-64*	42.0	42.0	42.1	42.2	42.2	42.3	42.4	42.4	42.4
School Loss Days										
School Loss Days, All Cause	*5-17*	10.8	10.7	10.7	10.6	10.5	10.5	10.4	10.4	10.4

[3] Zhang, L. *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, 45 *Atmos. Envt.* 6769-6776 (2011).

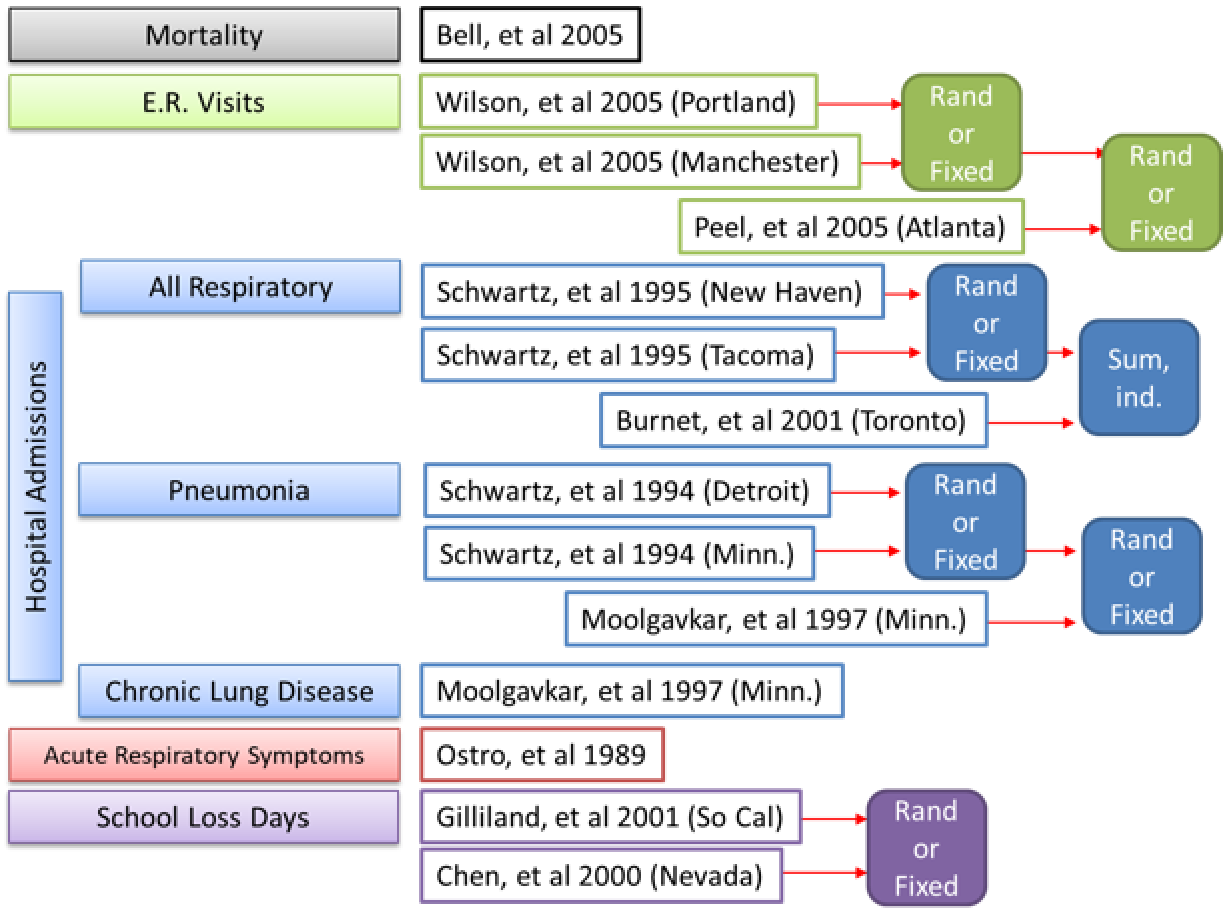
The US population data were based on estimates of populations in the corresponding year projected from 2010 block-level US Census data. The geographic extent of population was limited to the population that lives in the 12 full states in the OTR, the District of Columbia and the nine cities/counties 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 4. A similar breakdown by state is available upon request.

Selection of Health Impact Functions

There is some evidence of a relationship between long-term exposure to concentrations of ozone and premature respiratory mortality.[4] However, there remain questions as to whether long-term mortality has the same direct relationship to ozone exposure as short-term mortality since the literature on this was relatively sparse at the time of this study. Therefore, our BenMAP analysis 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 12.

[4] Jerrett *et al.*, Long-Term Ozone Exposure and Mortality, 360 *N. Engl. J. Med.* 1085-1095 (2009).

Figure 12: Aggregation of health effects studies



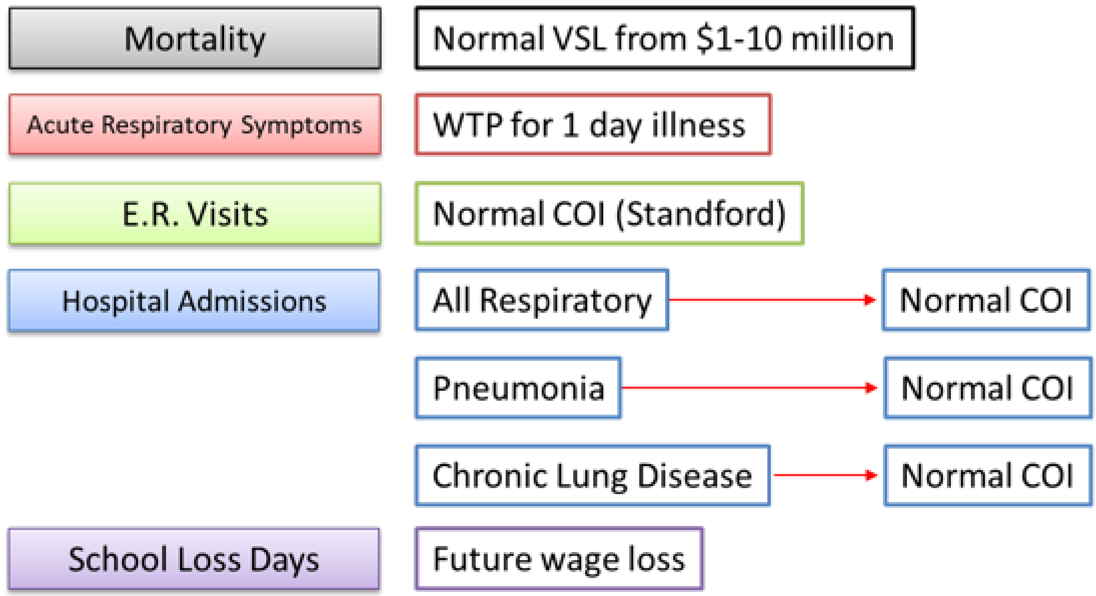
Baseline Incidence Rates

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 with 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. Exceptions were for school loss days where 2000 was the only data set available, and for 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 sums 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 13. 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 13: Aggregation of economic evaluations



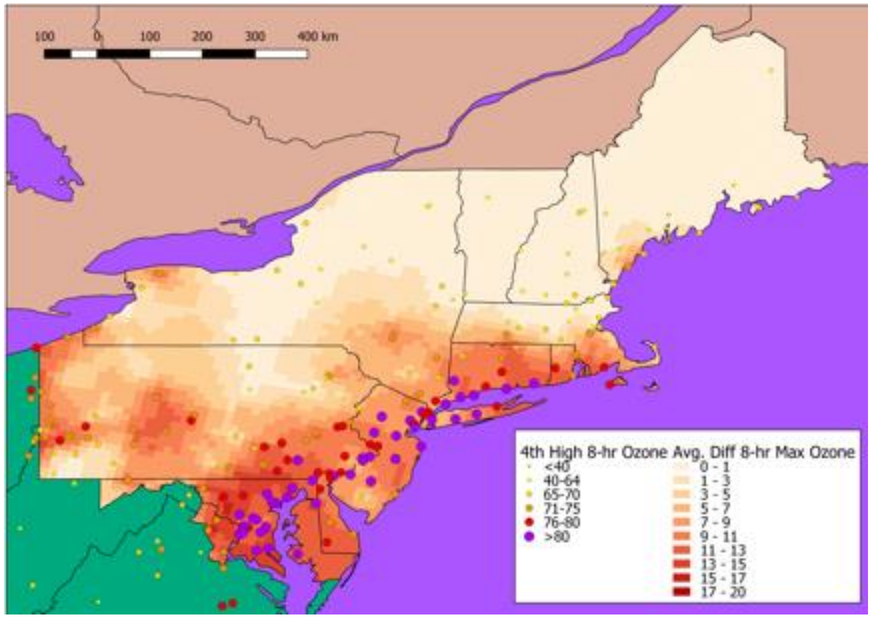


Figure 14: Change in avg. 8-hour max. ozone after roll back to 70 ppb using 2011 data

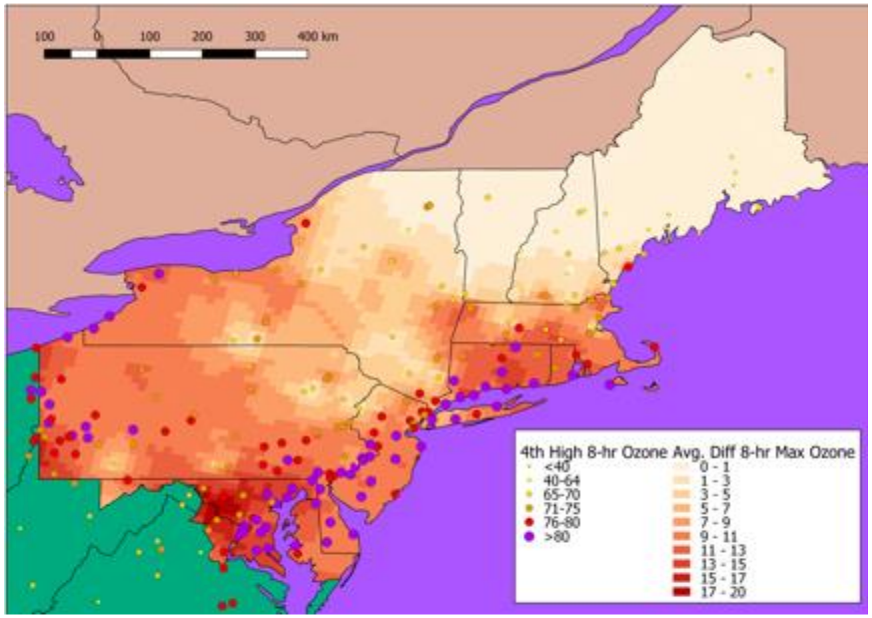


Figure 15: Change in avg. 8-hour max. ozone after roll back to 70 ppb using 2012 data

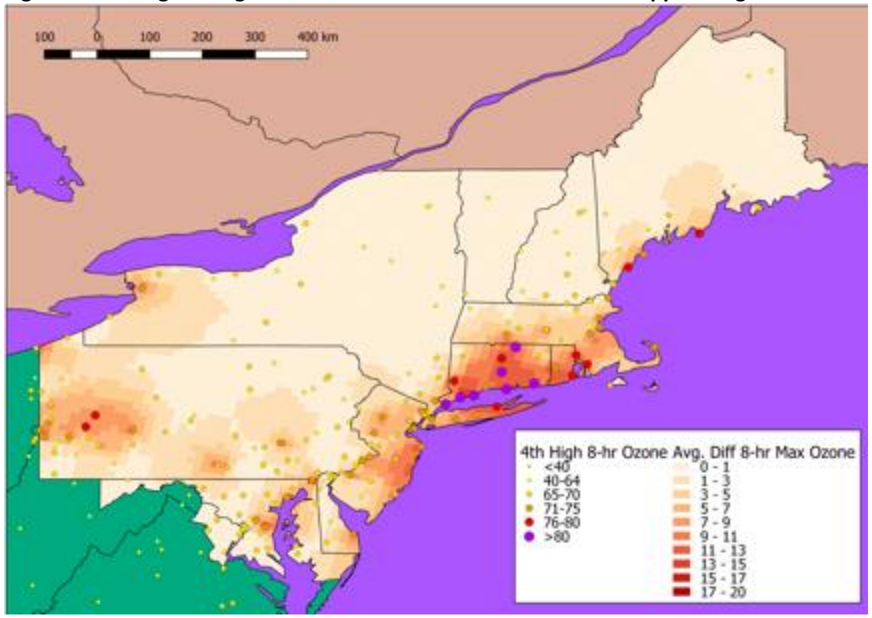


Figure 16: Change in avg. 8-hour max. ozone after roll back to 70 ppb using 2013 data

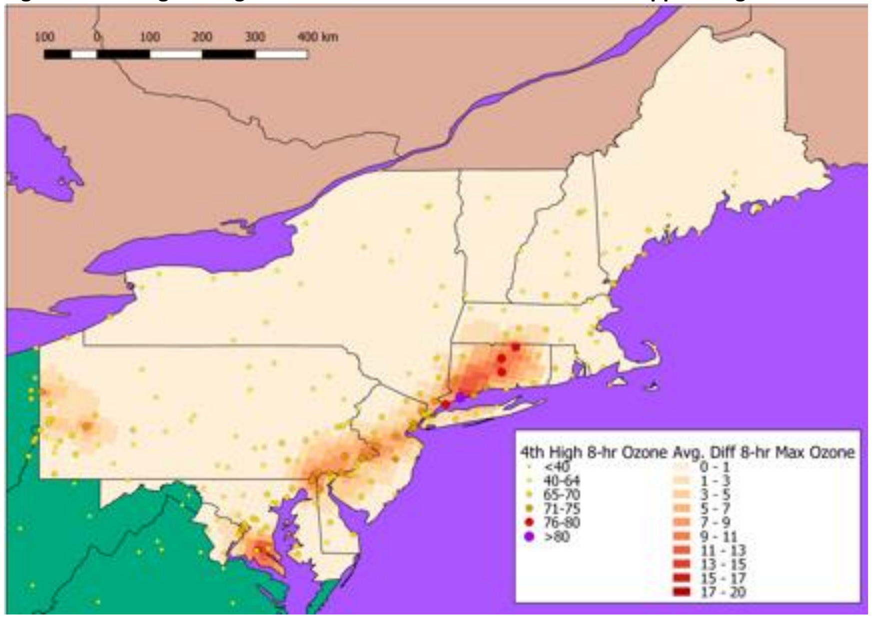


Figure 17: Change in avg. 8-hour max. ozone after roll back to 70 ppb using 2014 data

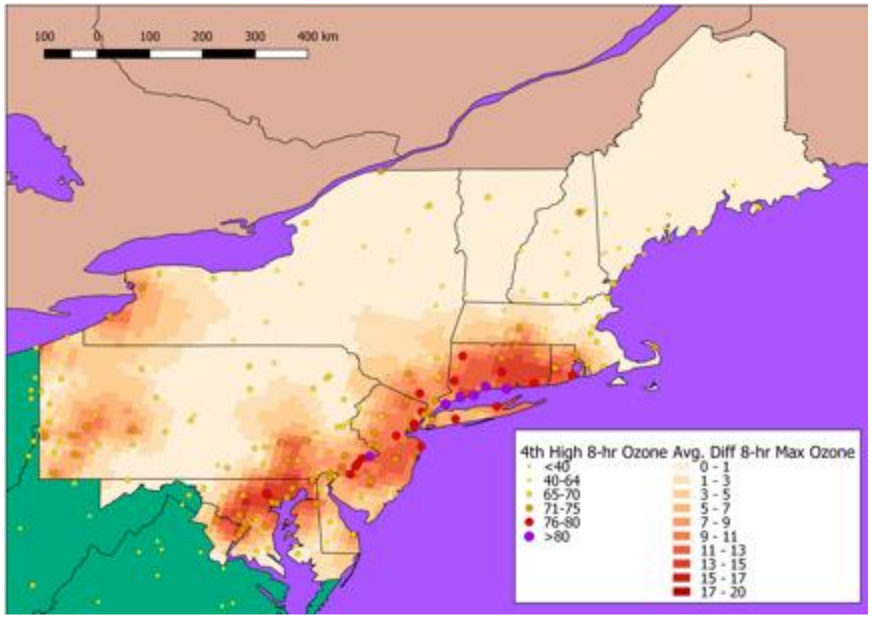


Figure 18: Change in avg. 8-hour max. ozone after roll back to 70 ppb using 2015 data

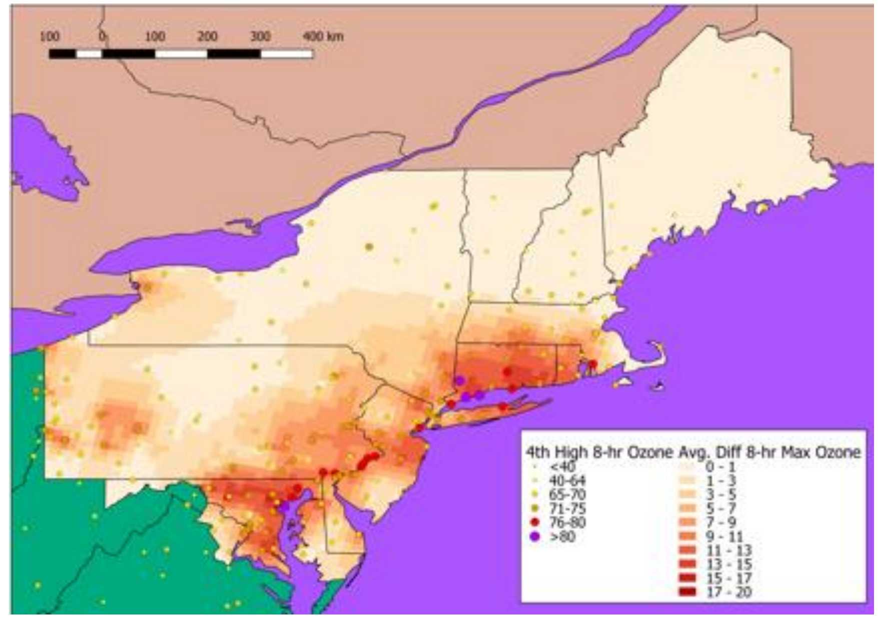


Figure 19: Change in avg. 8-hour max. ozone after roll back to 70 ppb using 2016 data

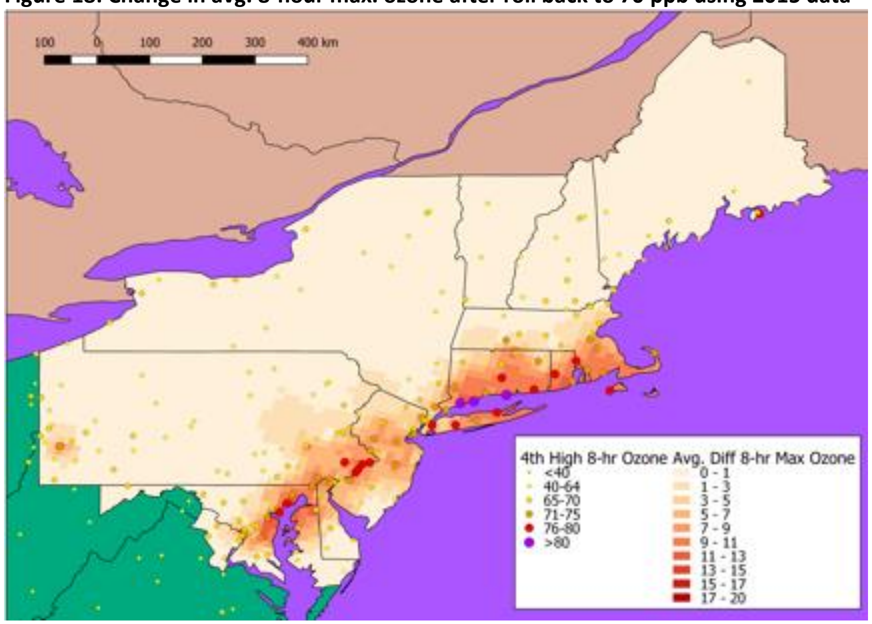


Figure 20: Change in avg. 8-hour max. ozone after roll back to 70 ppb using 2017 data

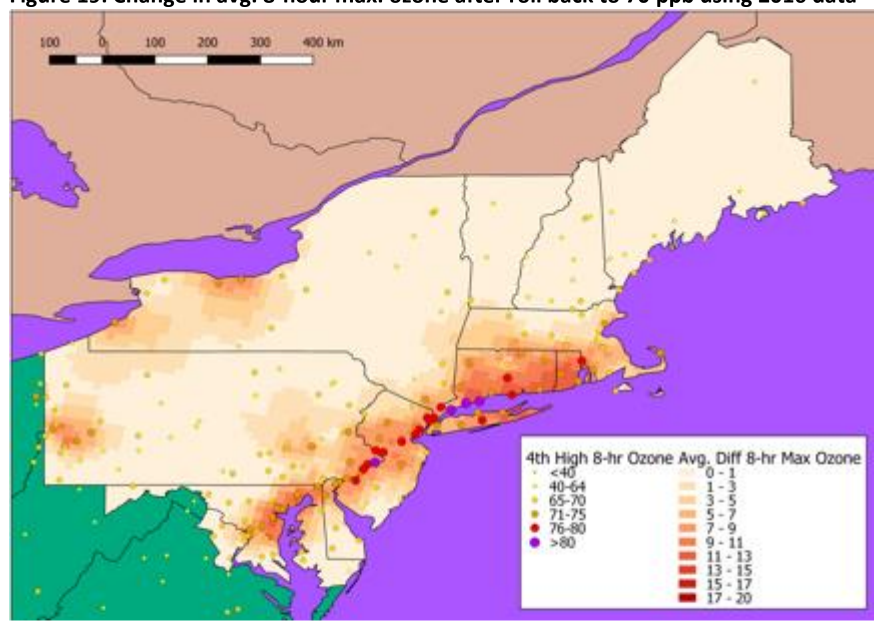


Figure 21: Change in avg. 8-hour max. ozone after roll back to 70 ppb using 2018 data

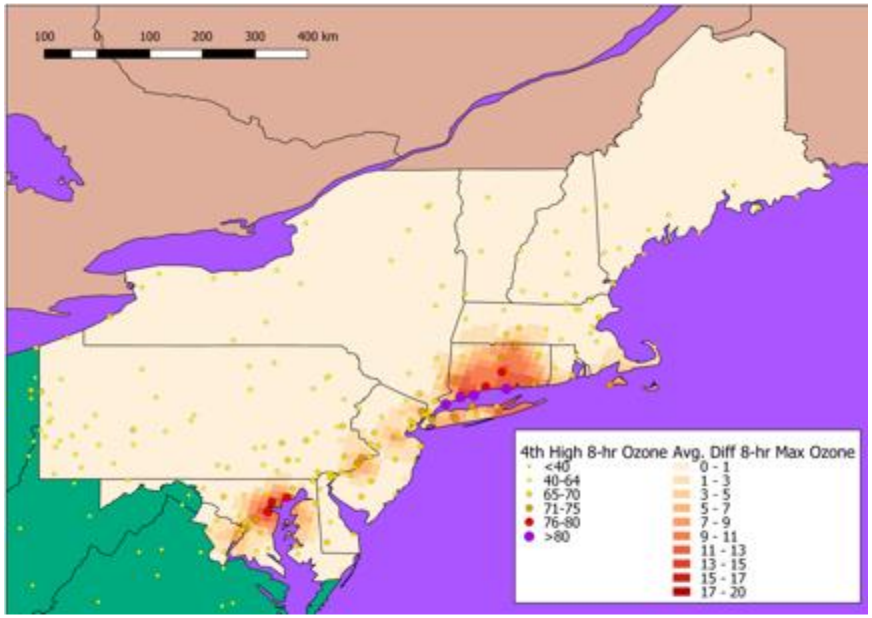


Figure 22: Change in avg. 8-hour max. ozone after roll back to 70 ppb using 2019 data

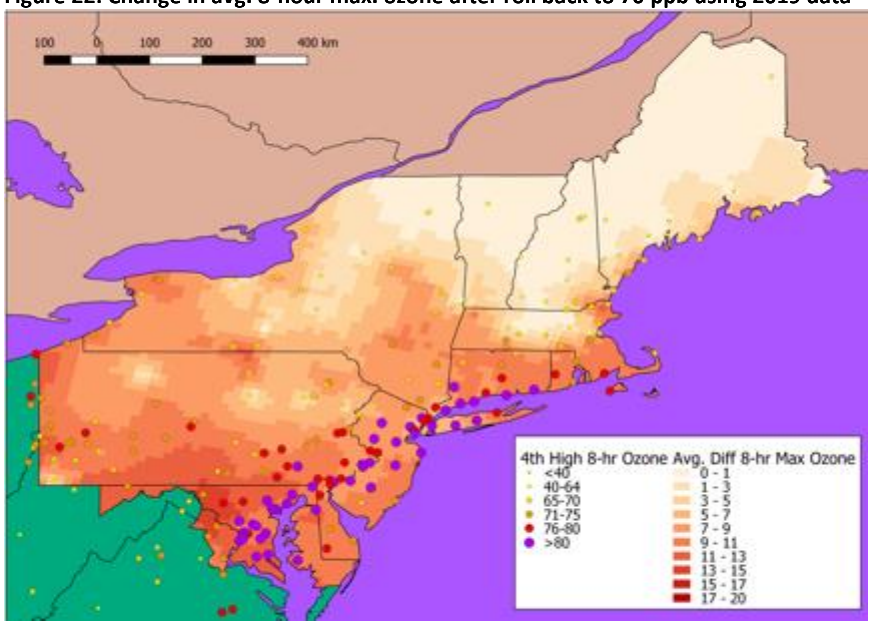


Figure 23: Change in avg. 8-hour max. ozone after roll back to 65 ppb using 2011 data

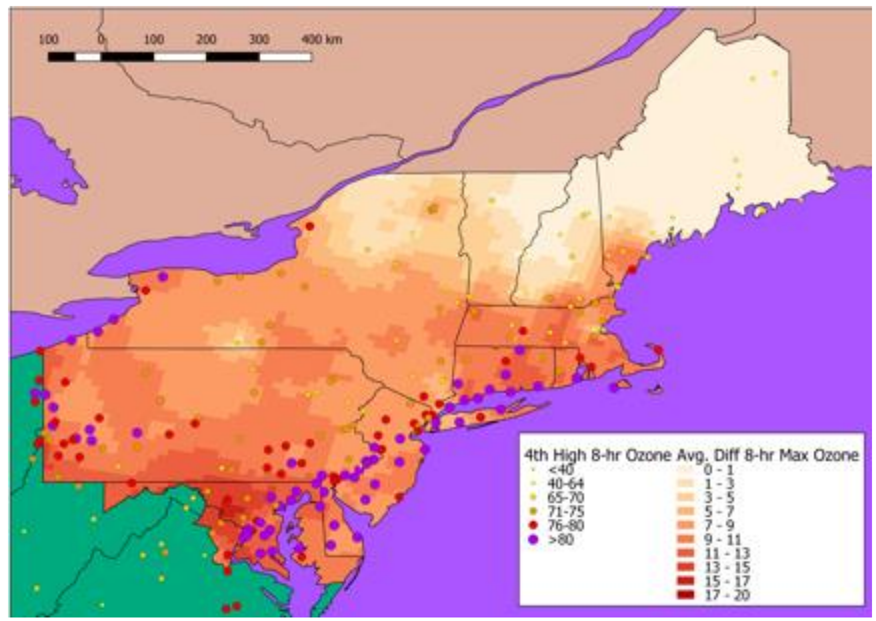


Figure 24: Change in avg. 8-hour max. ozone after roll back to 65 ppb using 2012 data

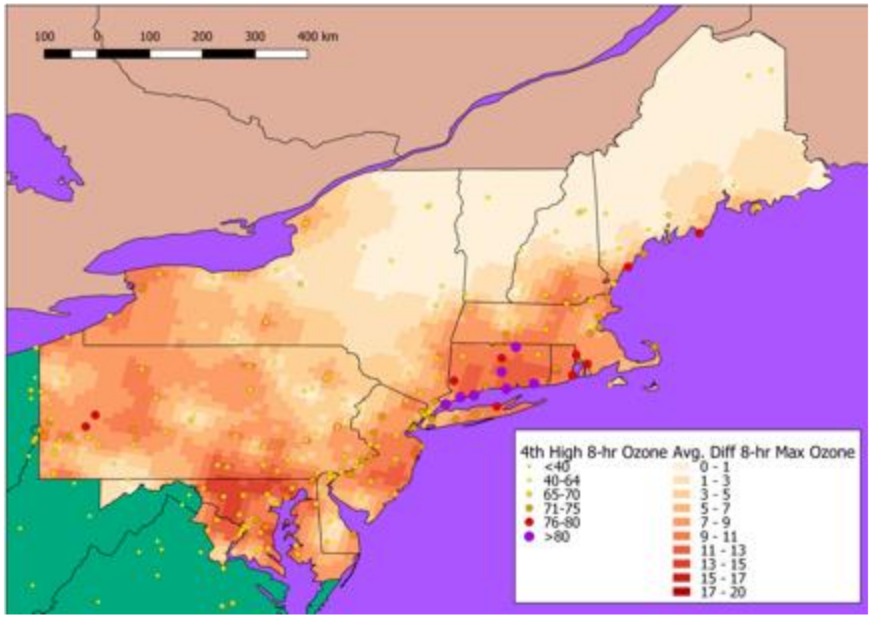


Figure 25: Change in avg. 8-hour max. ozone after roll back to 65 ppb using 2013 data

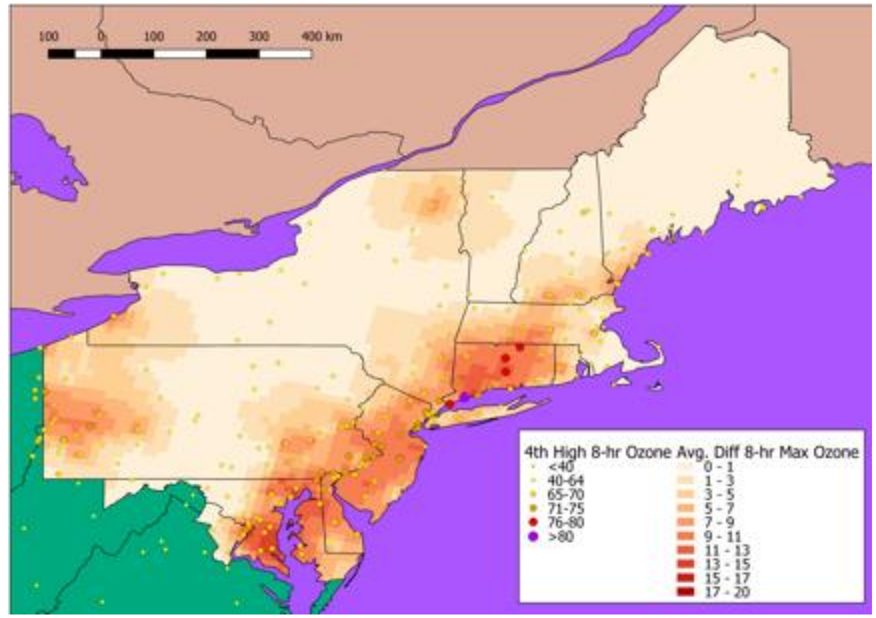


Figure 26: Change in avg. 8-hour max. ozone after roll back to 65 ppb using 2014 data

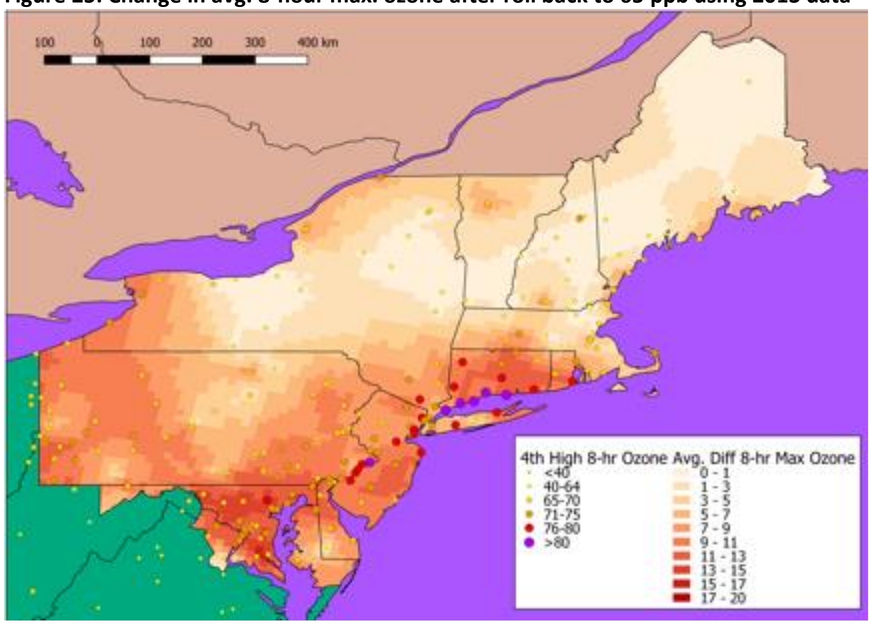


Figure 27: Change in avg. 8-hour max. ozone after roll back to 65 ppb using 2015 data

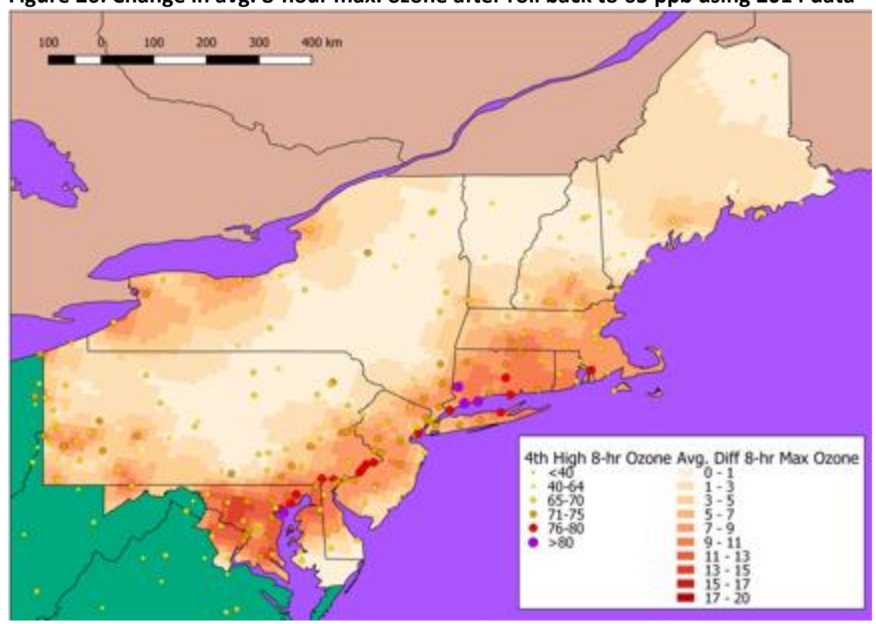


Figure 28: Change in avg. 8-hour max. ozone after roll back to 65 ppb using 2016 data

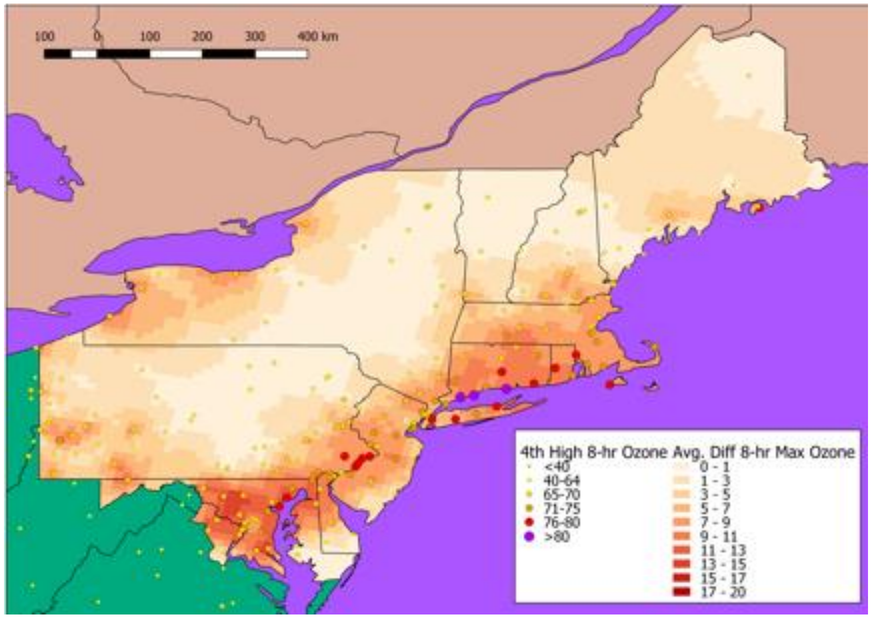


Figure 29: Change in avg. 8-hour max. ozone after roll back to 65 ppb using 2017 data

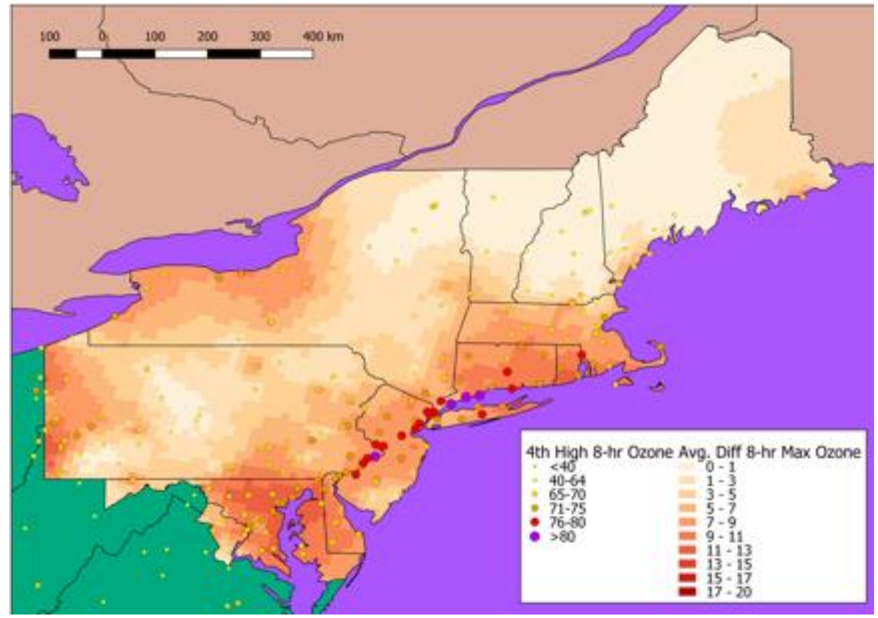


Figure 30: Change in avg. 8-hour max. ozone after roll back to 65 ppb using 2018 data

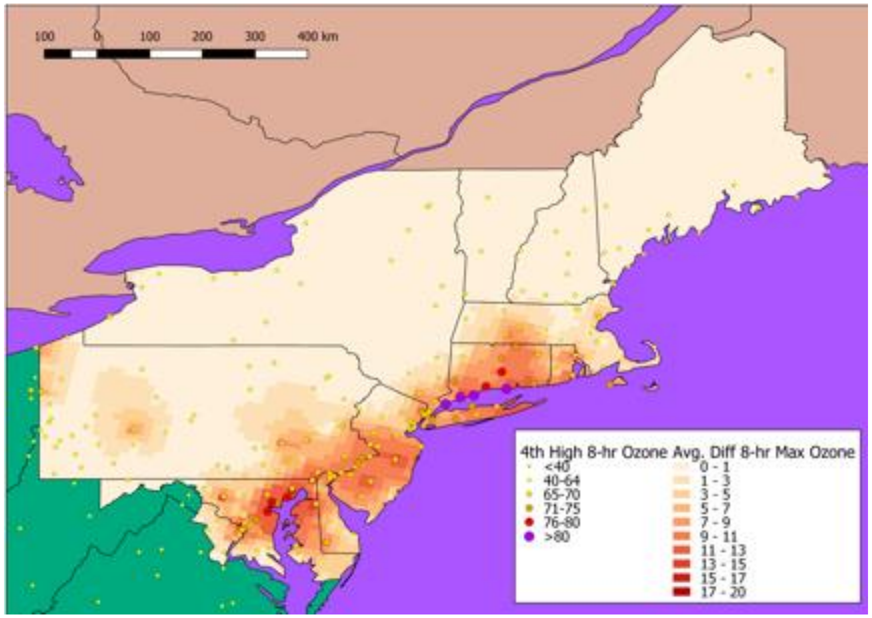


Figure 31: Change in avg. 8-hour max. ozone after roll back to 65 ppb using 2019 data

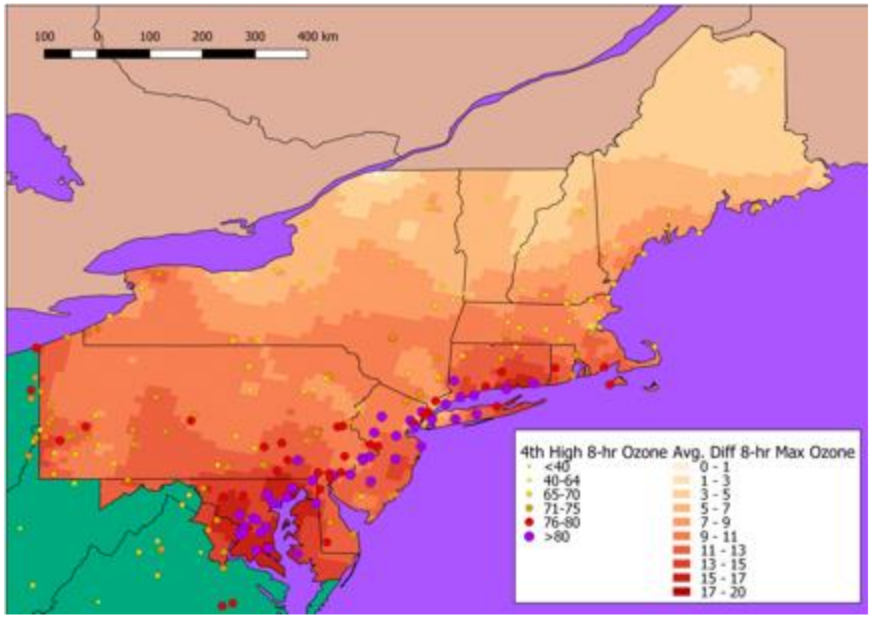


Figure 32: Change in avg. 8-hour max. ozone after roll back to 40 ppb using 2011 data

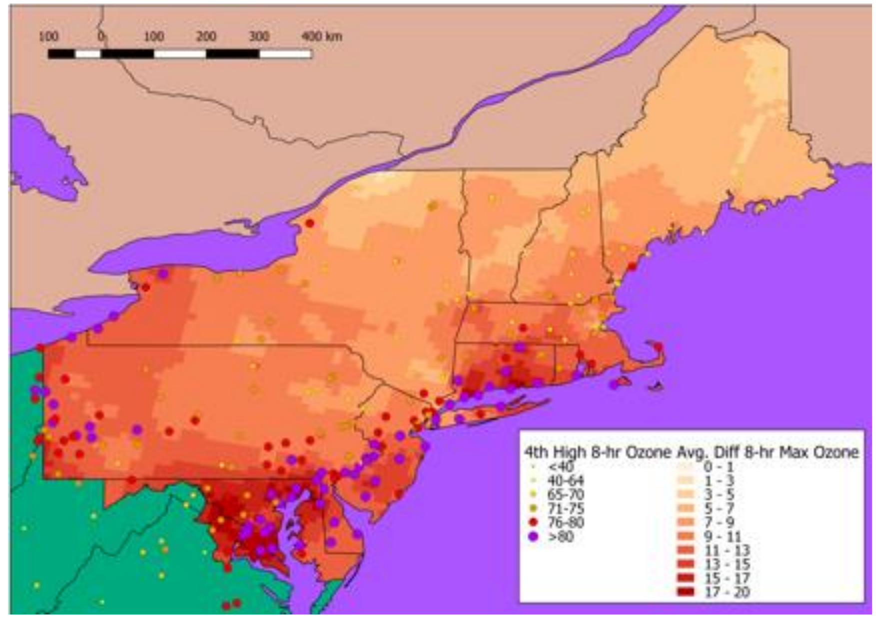


Figure 33: Change in avg. 8-hour max. ozone after roll back to 40 ppb using 2012 data

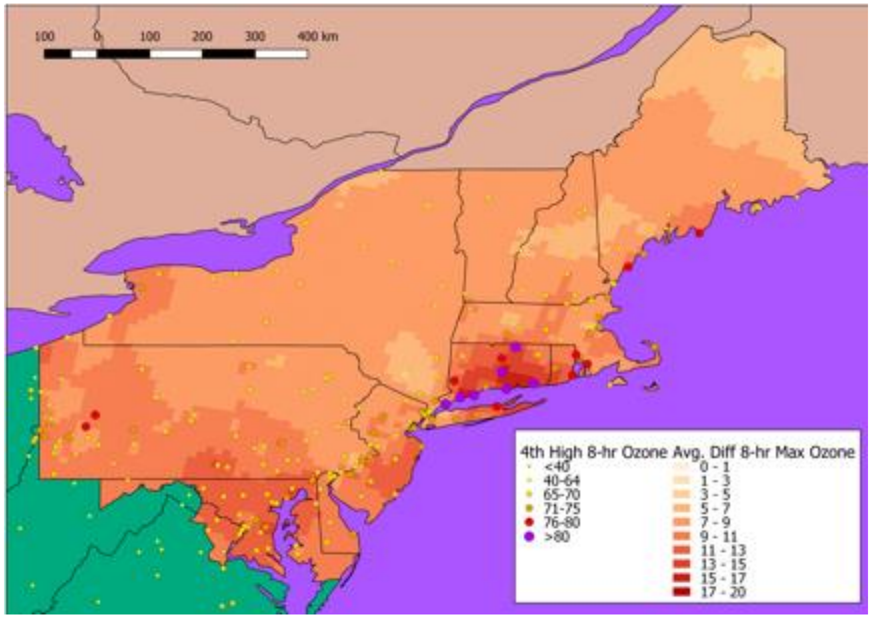


Figure 34: Change in avg. 8-hour max. ozone after roll back to 40 ppb using 2013 data

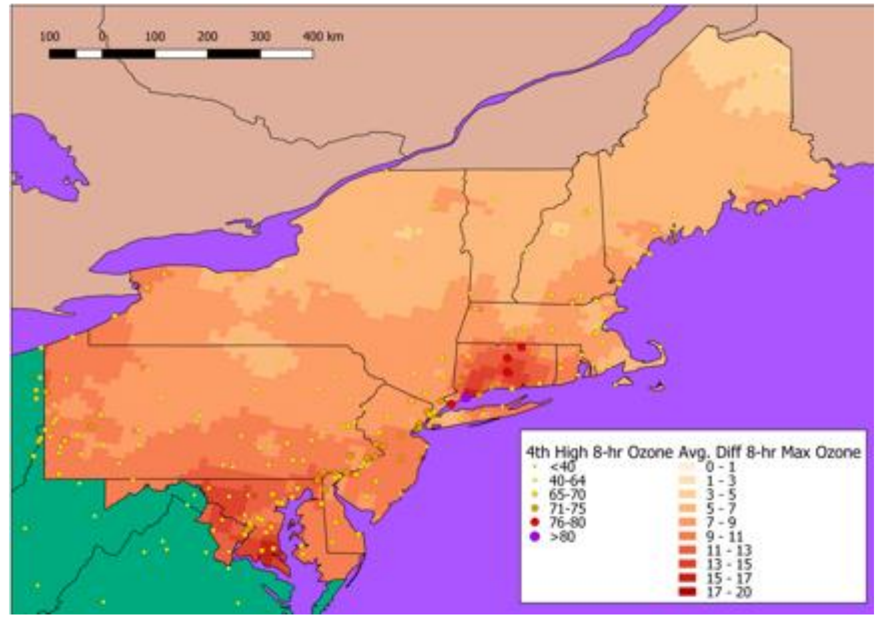


Figure 35: Change in avg. 8-hour max. ozone after roll back to 40 ppb using 2014 data

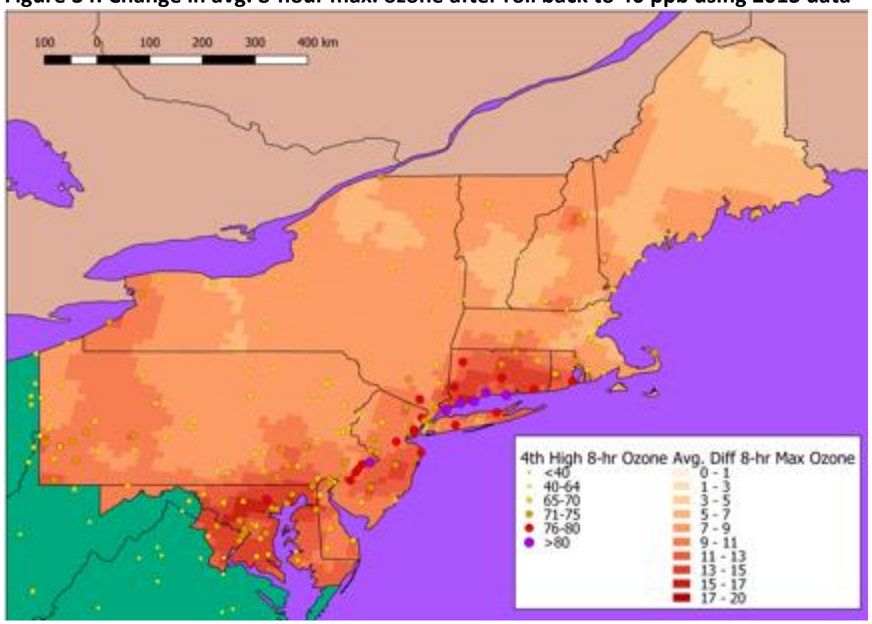


Figure 36: Change in avg. 8-hour max. ozone after roll back to 40 ppb using 2015 data

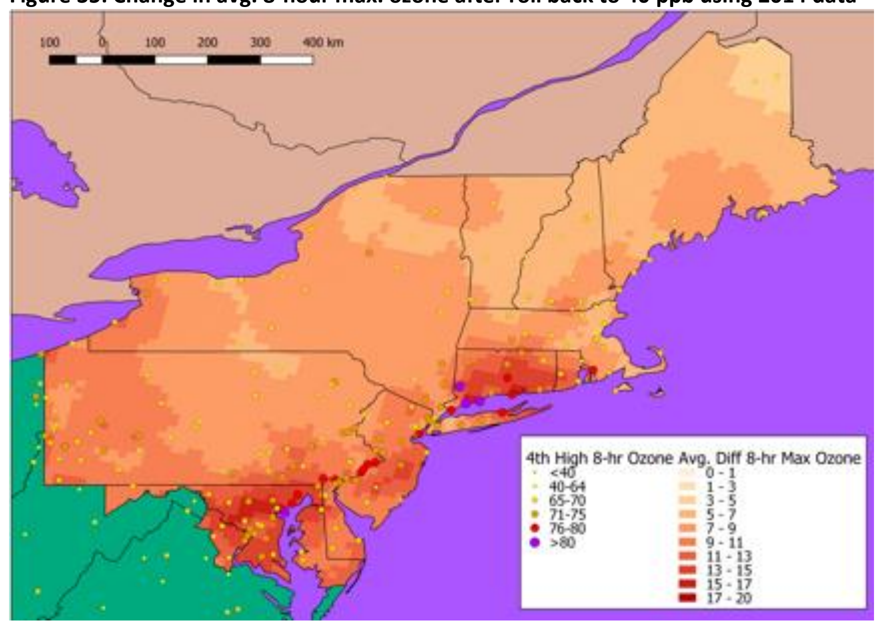


Figure 37: Change in avg. 8-hour max. ozone after roll back to 40 ppb using 2016 data

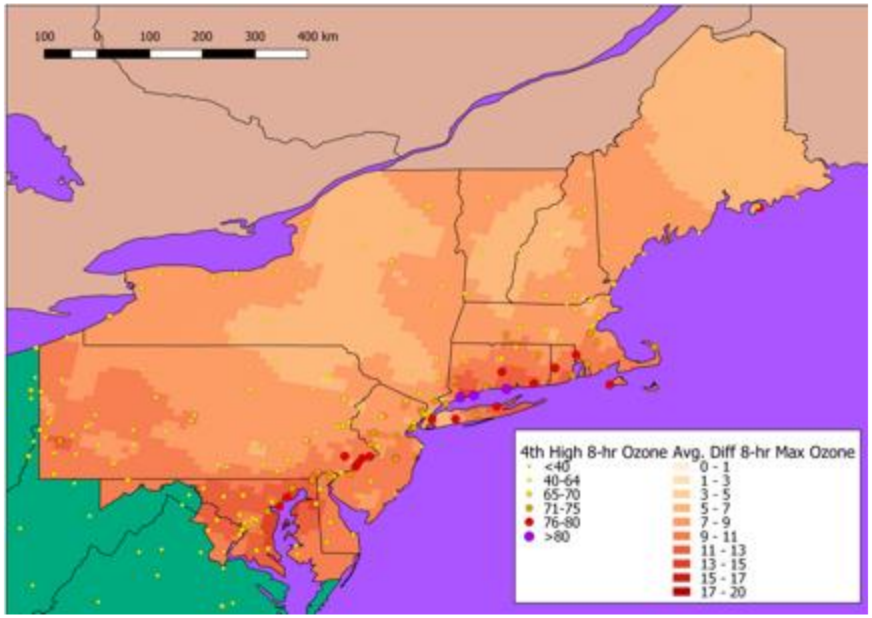


Figure 38: Change in avg. 8-hour max. ozone after roll back to 40 ppb using 2017 data

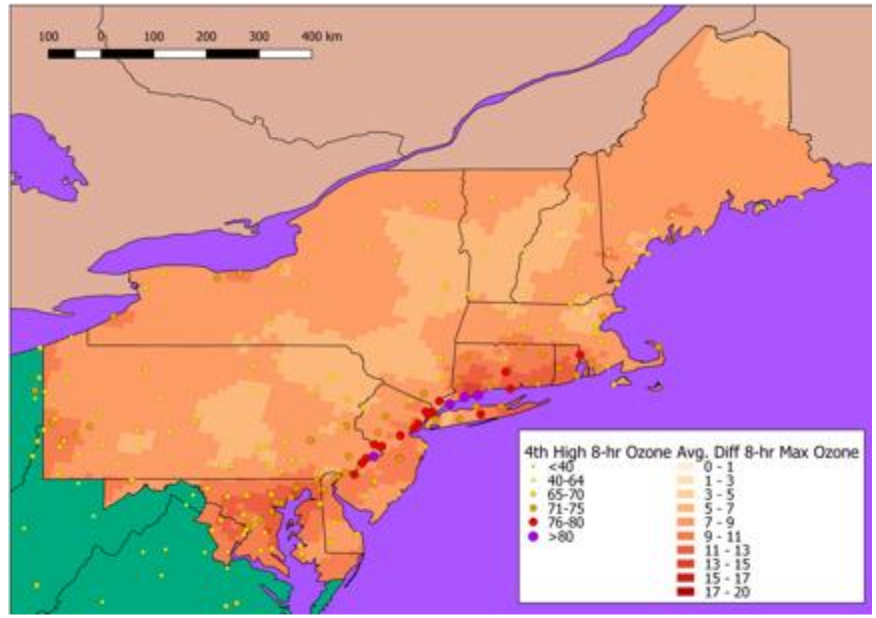


Figure 39: Change in avg. 8-hour max. ozone after roll back to 40 ppb using 2018 data

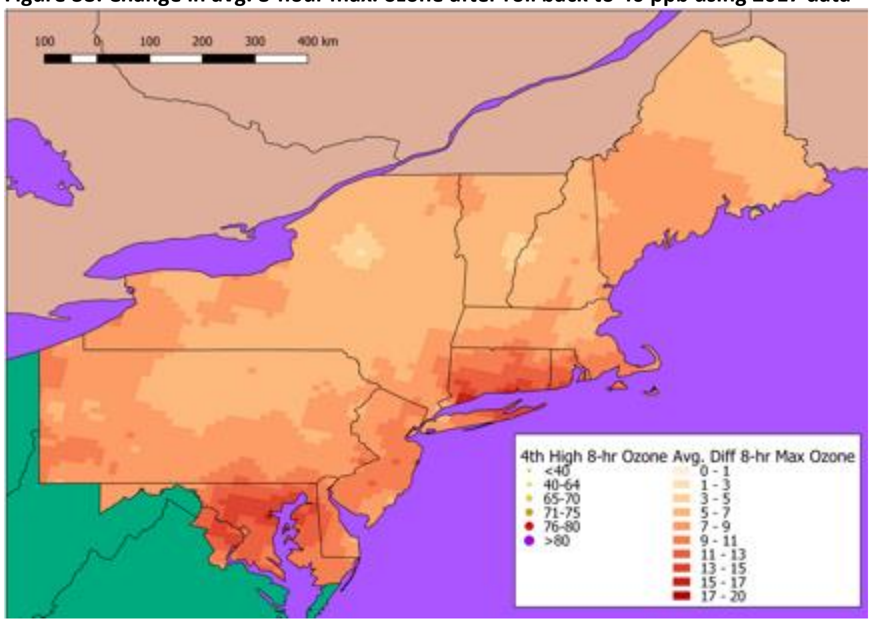


Figure 40: Change in avg. 8-hour max. ozone after roll back to 40 ppb using 2019 data

Results

Monitor Rollback

The preceding overview maps display the changes in average 8-hour maximum ozone concentrations in the OTR after being rolled back to 70 ppb (Figure 14 through Figure 22), to 60 ppb (Figure 23 through Figure 31), and to 40 ppb (Figure 32 through Figure 40).

The majority of the reductions in ozone levels in the 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 15) when they extended throughout central Pennsylvania, New York, and southern New England. Reductions in 2011 (Figure 14) 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 17), when even the Baltimore area saw no reductions.

The Pittsburgh area also saw reductions in the 70 ppb rollback scenarios except in 2014 (Figure 17) and 2019 (Figure 22). Isolated areas in western New York and central Pennsylvania also saw reductions in 2013 (Figure 16), 2015 (Figure 18), and 2016 (Figure 19).

In the 65 ppb scenarios for 2013 (Figure 25) through 2019 (Figure 31), the results resembled those in the 70 ppb scenario for 2011 and 2012. In 2011 (Figure 23) and 2012 (Figure 24), rolling back monitors to 65 ppb did not increase the areal extent of reductions much from the 70 ppb roll back scenario, with one exception – many of the 65 ppb scenarios for 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 21) and 2017 (Figure 20) rollbacks, the 2018 rollback for 65 ppb (Figure 30) saw more reductions than the 2017 rollback (Figure 29).

The entire region saw extensive and deep reductions in ozone levels in the 40 ppb rollback scenarios, including many rural areas in the region. The least reductions occurred in northern New York and northern New England, and the greatest reductions were again along the I-95 corridor.

Health Impacts

After processing the health impact functions, we estimated that if the entire OTR had 4th highest monitored 8-hour averages at or under 70 ppb, there would have been 600 to 2,400 fewer mortalities due to short-term ozone exposure in a given year (Table 5). As would be expected from the reductions in ozone levels, 2012 saw the most preventable mortalities if the 70 ppb NAAQS had been achieved, and 2014 saw the least. Figure 41 shows how reduced mortality changed in the OTR for each analysis year.

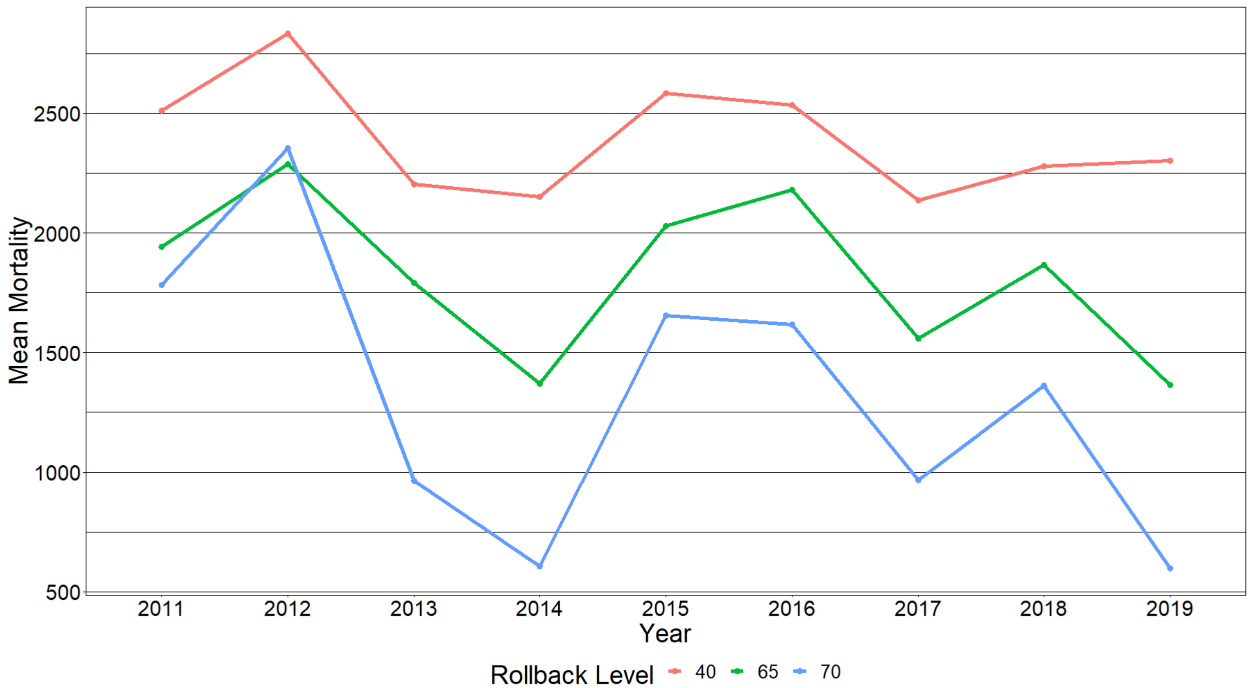


Figure 41: Change in mean mortality reduced by meeting the ozone NAAQS for each analysis year in the OTR

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 7). 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 with the lowest decreases in mortality in the 70 ppb scenario (2013, 2015, 2017). Years with higher magnitudes of decreased mortality in the 70 ppb scenario did not see the same doubling of benefits in reduced mortality from achieving a 65 ppb level (2011, 2015, 2016, and 2018). In this case, the increase in the magnitude of reduced mortality was more in the range of a 30% to 50%. This would be expected since there more areas 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 affected by the algorithm in addition to the lowering of the ozone levels.

Emergency room visits for asthma related conditions were estimated not to be significantly different than 0.

The same pattern of results occurred for the other health endpoints as mortality, with the magnitude of hospital admissions for 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 to 2019 for having met 70 ppb, 65 ppb, and 40 ppb are shown in Figure 42, Figure 43, and Figure 44, respectively.

Looking specifically at the 70 ppb scenario, in 2013 and 2014 states in the southern OTR (Virginia, Maryland, Delaware) and the 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 among the higher population areas 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 Impacts

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 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 by state for having met 70 ppb, 65 ppb, and 40 ppb in the OTR, excluding emergency room visits and minor restricted activity days, are shown for each year from 2011 to 2019 in Figure 45, Figure 46, and Figure 47, 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 influenced by inflation than the change in mortality. A full breakdown of the economic impacts is in Table 6, 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 face increased risk of premature death and decreased quality of life due to the health effects of ozone. These health effects come with an economic price tag as well. Furthermore, because there is currently no known "no affects" threshold for avoiding adverse ozone health impacts, achieving ozone levels below the current 70 ppb ozone NAAQS likely would generate greater health benefits.

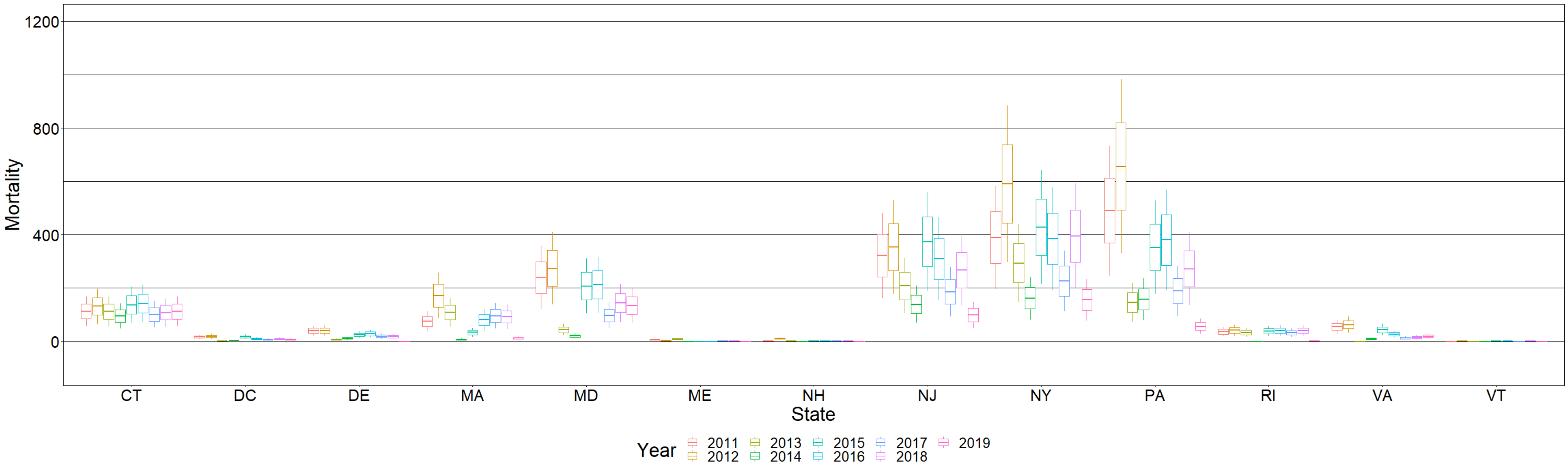


Figure 42: Estimated state mortalities that could have been avoided by meeting a 70 ppb threshold from 2011-2019

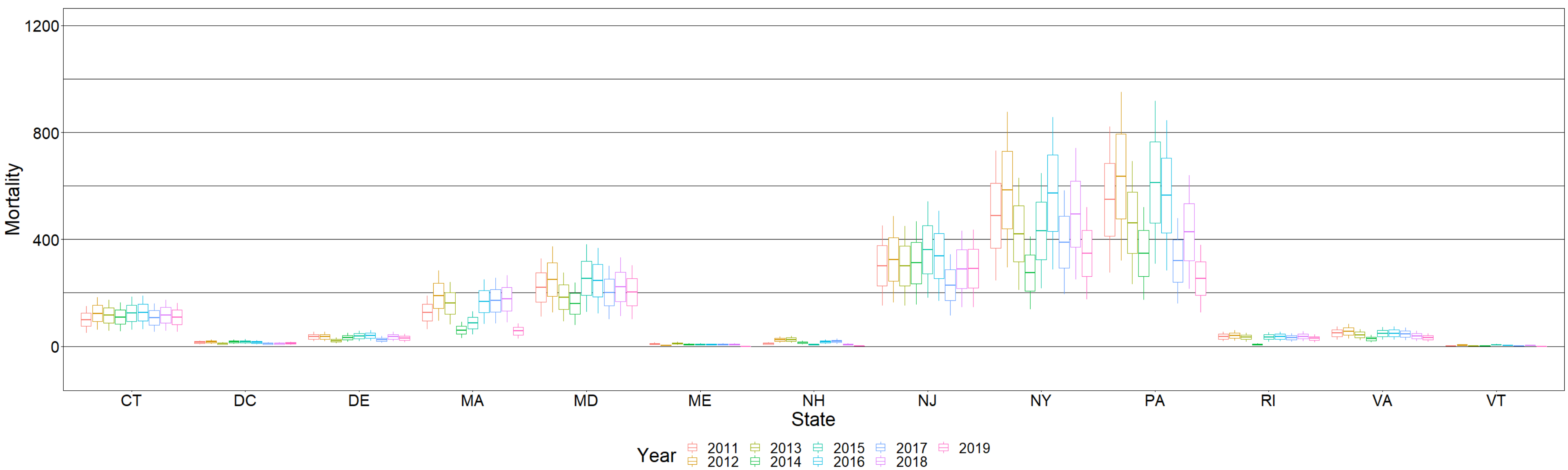


Figure 43: Estimated state mortalities that could have been avoided by meeting a 65 ppb threshold from 2011-2019

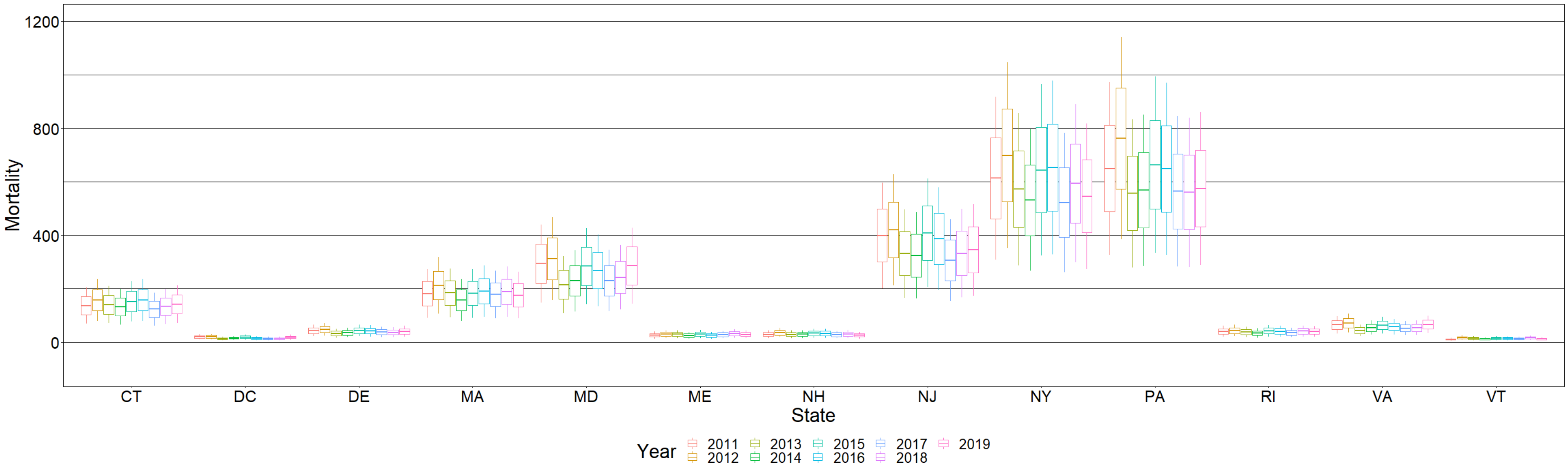


Figure 44: Estimated state mortalities that could have been avoided by meeting a 40 ppb threshold from 2011-2019

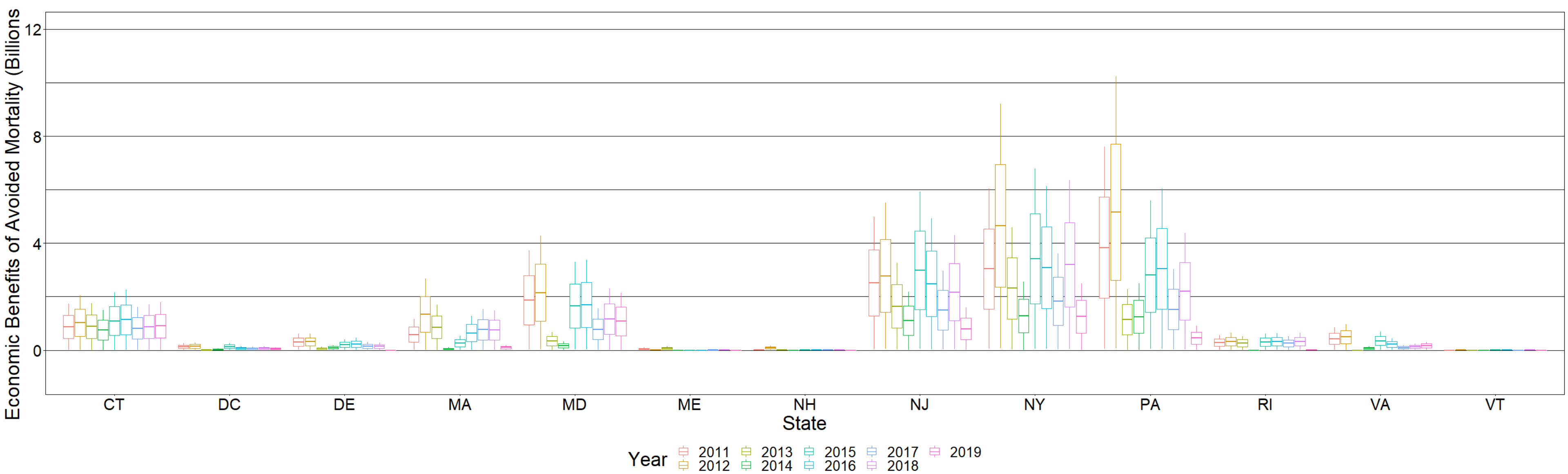


Figure 45: Estimated state level economic benefits that could have occurred by meeting a 70 threshold NAAQS from 2011-2019

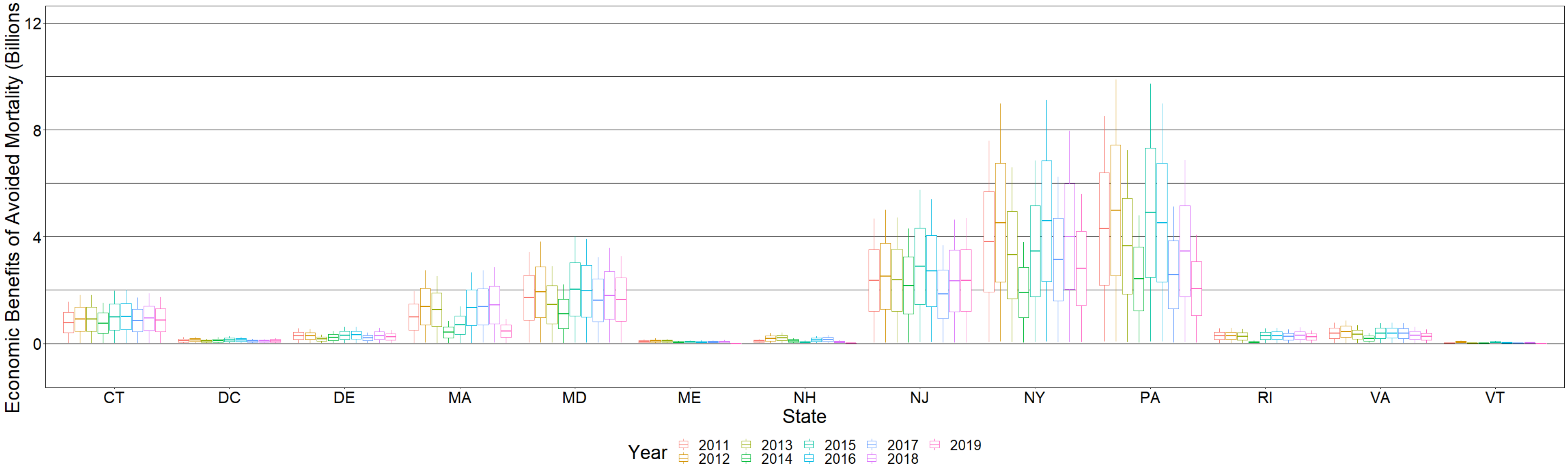


Figure 46: Estimated state level economic benefits that could have occurred by meeting a 65 ppb threshold from 2011-2019

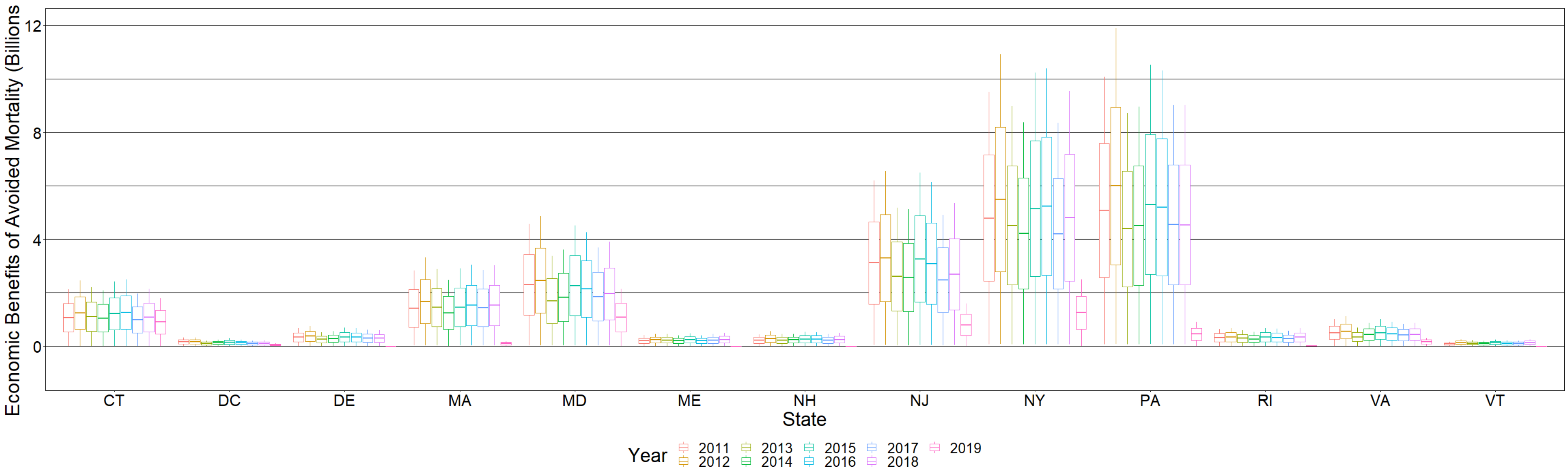


Figure 47: Estimated state level economic benefits that could have occurred by meeting a 40 ppb threshold from 2011-2019

Table 5: Estimated ozone-related health impacts following monitor rollback to 40, 65, and 70 ppb for 2011-2019 in the OTR

	2011			2012			2013			2014			2015			2016			2017			2018			2019		
	40	65	70	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[5]																											
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	2,303	1,365	597
-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	1,156	685	299
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	3,449	2,045	895
E.R. Visits																											
Asthma[6]																											
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	2,324	1,628	684
-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	-465	-326	-138
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	5,112	3,583	1,505
Hospital Admissions																											
All Respiratory[7]																											
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	4,753	2,943	1,273
-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	901	650	257
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	8,604	5,237	2,288
Chronic Lung Disease (less Asthma)[8]																											
Mean	1,464	1,132	1,043	1,660	1,345	1,376	1,320	1,076	589	1,297	821	358	1,559	1,213	985	1,543	1,318	988	1,322	971	612	1,418	1,164	834	1,458	863	378
-2σ	461	351	325	525	420	431	409	332	180	402	253	109	488	377	307	482	409	306	410	299	188	442	361	258	451	266	115
2σ	2,467	1,912	1,761	2,795	2,270	2,321	2,230	1,820	998	2,192	1,390	607	2,631	2,050	1,664	2,605	2,227	1,669	2,234	1,642	1,035	2,395	1,966	1,409	2,465	1,460	641
Pneumonia[9]																											
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	1,437	834	369
-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	621	360	158
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	2,253	1,308	580
Acute Respiratory Symptoms																											
Minor Restricted Activity Days[10]																											
Mean	5027 K	3854 K	3657 K	5499 K	4453 K	4616 K	4225 K	3487 K	1864 K	4120 K	2696 K	1253 K	4855 K	3796 K	3262 K	4693 K	4074 K	3058 K	3890 K	3003 K	1851 K	4106 K	3413 K	2592 K	4134 K	2616 K	1165 K
-2σ	2282 K	1737 K	1652 K	2500 K	2012 K	2090 K	1904 K	1567 K	835 K	1856 K	1211 K	560 K	2197 K	1712 K	1473 K	2122 K	1837 K	1377 K	1753 K	1350 K	830 K	1856 K	1538 K	1169 K	1862 K	1177 K	520 K
2σ	7773 K	5970 K	5661 K	8498 K	6893 K	7142 K	6546 K	5407 K	2893 K	6384 K	4182 K	1945 K	7513 K	5880 K	5052 K	7264 K	6311 K	4739 K	6027 K	4656 K	2871 K	6356 K	5287 K	4016 K	6406 K	4056 K	1810 K
School Loss Days																											

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[6] Wilson *et al.*, Air Pollution, Weather, and Respiratory Emergency Room Visits in Two Northern New England Cities: An Ecological Time-Series Study, 97 *Envtl. Res.* 312-321 (2005); Peel *et al.*, Ambient Air Pollution and Respiratory Emergency Department Visits, 16 *Epidemiology* 164-174 (2005).

[7] Burnett *et al.*, Association between Ozone and Hospitalization for Acute Respiratory Diseases in Children Less than 2 Years of Age, 153 *Am. J. Epidemiology* 444–452 (2001); Schwartz, Short Term Fluctuations in Air Pollution and Hospital Admissions of the Elderly for Respiratory Disease, 50 *Thorax* 531-538 (1995).

[8] Moolgavkar, Luebeck, and Anderson, Air Pollution and Hospital Admissions for Respiratory Causes in Minneapolis-St. Paul and Birmingham, 8 *Epidemiology* 364-370 (1997).

[9] *Ibid.*; Schwartz, Air Pollution and Hospital Admissions for the Elderly in Detroit, Michigan, 150 *Am. J. Resp. Crit. Care Med.* 648-655 (1994); Schwartz, PM10 Ozone, and Hospital Admissions for the Elderly in Minneapolis-St. Paul, Minnesota, 49 *Archives Envtl. Health: An Intl. Journal* 366-374 (1994).

[10] Ostro and Rothschild, Air Pollution and Acute Respiratory Morbidity: An Observational Study of Multiple Pollutants, 50 *Envtl. Res.* 238-247 (1989).

	2011			2012			2013			2014			2015			2016			2017			2018			2019		
	40	65	70	40	65	70	40	65	70	40	65	70	40	65	70	40	65	70	40	65	70	40	65	70	40	65	70
All Causes[11]																											
Mean	1499 K	1123 K	1068 K	1632 K	1290 K	1341 K	1208 K	1001 K	527 K	1170 K	763 K	351 K	1369 K	1072 K	918 K	1316 K	1140 K	860 K	1083 K	833 K	511 K	1142 K	947 K	715 K	1148 K	727 K	320 K
-2σ	521 K	454 K	432 K	568 K	522 K	542 K	489 K	405 K	213 K	473 K	308 K	142 K	553 K	434 K	371 K	532 K	461 K	348 K	438 K	337 K	207 K	462 K	383 K	289 K	464 K	294 K	130 K
2σ	2477 K	1792 K	1704 K	2697 K	2059 K	2139 K	1928 K	1597 K	840 K	1867 K	1217 K	559 K	2184 K	1711 K	1464 K	2100 K	1819 K	1372 K	1727 K	1329 K	815 K	1822 K	1511 K	1141 K	1831 K	1160 K	511 K

Table 6: Estimated ozone-related economic impacts (2010$) following monitor rollback to 70, 65, and 40 ppb for 2011-2019 in the OTR

	2011			2012			2013			2014			2015			2016			2017			2018			2019		
	40	65	70	40	65	70	40	40	65	70	65	70	40	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	$4,838	$11,056	$4,838
-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	$68	$161	$68
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	$9,608	$21,951	$9,608
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	$0.3	$0.6	$0.3
-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	-$0.1	-$0.1	-$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	$0.6	$1.4	$0.6
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	$39.8	$91.4	$39.8
-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	-$7.8	-$16.9	-$7.8
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	$87.3	$199.7	$87.3
Chronic Lung Disease (less Asthma)																											
Mean	$33.3	$25.8	$23.8	$37.8	$30.1	$31.3	$30.0	$24.5	$13.4	$29.5	$18.7	$8.2	$35.5	$27.6	$22.5	$35.1	$30.0	$22.5	$30.1	$22.1	$13.9	$32.3	$26.5	$19.0	$8.6	$19.7	$8.6
-2σ	$10.5	$8.0	$7.4	$12.0	$9.4	$9.8	$9.3	$7.6	$4.1	$9.1	$5.8	$2.5	$11.1	$8.6	$7.0	$11.0	$9.3	$7.0	$9.3	$6.8	$4.3	$10.1	$8.2	$5.9	$2.6	$6.1	$2.6
2σ	$56.2	$43.5	$40.1	$63.6	$50.8	$52.9	$50.8	$41.4	$22.7	$49.9	$31.7	$13.8	$59.9	$46.7	$37.9	$59.3	$50.7	$38.0	$50.8	$37.4	$23.6	$54.5	$44.8	$32.1	$14.6	$33.3	$14.6
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	$10.1	$22.8	$10.1
-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	$4.3	$9.8	$4.3
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	$15.8	$35.7	$15.8
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	$37.6	$84.5	$37.6
-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	-$12.1	-$26.9	-$12.1
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	$87.3	$195.9	$87.3
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	$30.7	$69.8	$30.7
-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	$12.5	$28.3	$12.5
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	$49.0	$111.2	$49.0

[11] Chen *et al.*, Elementary School Absenteeism and Air Pollution, 12 *Inhal. Toxic.* 997-1016 (2008); Gilliland *et al.*, The Effects of Ambient Air Pollution on School Absenteeism Due to Respiratory Illnesses, 12 *Epidemiology* 43-54 (2001).

Table 7: 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	Diarrheal 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	Anemia	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	-
Esophagus 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	-