United States
Environmental Protection
Agency

Office of Water
Washington, DC 20460

EPA-821-R-20-003
August 28, 2020

Benefit and Cost Analysis for Revisions to the Effluent Limitations Guidelines and Standards for the Steam Electric Power Generating Point Source Category

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U.S. Environmental Protection Agency
Office of Water (4303T)
Engineering and Analysis Division
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Abbreviations

ACE	Affordable Clean Energy
ACS	American Community Survey
ADD	Average daily dose
As	Arsenic
ATSDR	Agency for Toxic Substances and Disease Registry
BA	Bottom ash
BAT	Best available technology economically achievable
BCA	Benefit-cost analysis
BEA	Bureau of Economic Analysis
BenMAP-CE	Environmental Benefits Mapping and Analysis Program—Community Edition
BLS	Bureau of Labor Statistics
BMP	Best management practices
BOD	Biochemical oxygen demand
BW	Body weight
CAMx	Comprehensive Air Quality Model with Extensions
CBG	Census Block Group
CCI	Construction Cost Index
CCME	Canadian Council of Ministers of the Environment
CCR	Coal combustion residuals
CDC	Center for Disease Control
CFR	Code of Federal Regulations
CO_2	Carbon dioxide
COD	Chemical oxygen demand
COI	Cost-of-illness
COPD	Chronic obstructive pulmonary disease
CPI	Consumer Price Index
CWA	Clean Water Act
D-FATE	Downstream Fate and Transport Equations
DBP	Disinfection byproduct
DBPR	Disinfectants and Disinfection Byproduct Rule
DCN	Document Control Number
DICE	Dynamic Integrated Climate and Economy
DO	Dissolved oxygen
E2RF1	Enhanced River File 1
EA	Environmental Assessment
EC	Elemental carbon
ECI	Employment Cost Index
ECOS	Environmental Conservation Online System
EGU	Electricity generating unit
EJ	Environmental justice
ELGs	Effluent limitations guidelines and standards
EO	Executive Order
EPA	United States Environmental Protection Agency
EROM	Enhanced Runoff Method

ESA	Endangered Species Act
FC	Fecal coliform
FCA	Fish consumption advisories
FGD	Flue gas desulfurization
FUND	Climate Framework for Uncertainty, Negotiation, and Distribution
FR	Federal Register
GDP	Gross Domestic Product
GHG	Greenhouse gas
GIS	Geographic Information System
HAP	Hazardous air pollutant
HCl	Hydrogen chloride
Hg	Mercury
HRTR	High Residence Time Reduction
HUC	Hydrologic unit code
IAM	Integrated assessment model
IBI	Index of biotic integrity
IEUBK	Integrated Exposure, Uptake, and Biokinetics
IPCC	Intergovernmental Panel on Climate Change
IPM	Integrated Planning Model
ISA	Integrated science assessment
IRIS	Integrated Risk Information System
IQ	Intelligence quotient
LADD	Lifetime average daily dose
LML	Lowest measured level
LRTR	Low Residence Time Reduction
MATS	Mercury and Air Toxics Standards
MCL	Maximum contaminant level
MCLG	Maximum contaminant level goal
MDA1	Maximum daily 1-hour average
MDA8	Maximum daily 8-hour average
MGD	Million gallons per day
MRM	Meta-regression model
MWTP	Marginal willingness-to-pay
NAAQS	National Ambient Air Quality Standards
NEI	National Emissions Inventory
NERC	North American Electric Reliability Corporation
NHD	National Hydrography Dataset
NLCD	National Land Cover Dataset
NLFA	National Listing Fish Advisory
NOAA	National Oceanic and Atmospheric Administration
NO_X	Nitrogen oxides
NPDES	National Pollutant Discharge Elimination System
NRWQC	National Recommended Water Quality Criteria
NWIS	National Water Information System
O3	Ozone
O3V	Ozone formed in VOC-limited chemical regimes

O3N	Ozone formed in NO_X-limited chemical regimes
OA	Organic aerosol
O&M	Operation and maintenance
OMB	Office of Management and Budget
OSAT/APCA	Ozone Source Apportionment Technique/Anthropogenic Precursor Culpability Assessment
PACE	Policy Analysis of the Greenhouse Gas Effect
Pb	Lead
PbB	Blood lead concentration
$PM_{2.5}$	Particulate matter (fine inhalable particles with diameters 2.5 µm and smaller)
PM_{10}	Particulate matter (inhalable particles with diameters 10 µm and smaller)
ppm	parts per million
PSAT	Particulate Source Apportionment Technique
PSES	Pretreatment Standards for Existing Sources
PV	Present value
PWS	Public water system
QA	Quality assurance
QC	Quality control
RIA	Regulatory Impact Analysis
SAB-HES	Science Advisory Board Health Effect Subcommittee
SBREFA	Small Business Regulatory Enforcement Fairness Act
SC-CO_2	Social cost of carbon
SDWIS	Safe Drinking Water Information System
Se	Selenium
SO_2	Sulfur dioxide
SPARROW	SPAtially Referenced Regressions On Watershed attributes
SSC	Suspended solids concentration
SWFSC	Southwest Fisheries Science Center
T&E	Threatened and endangered
TDD	Technical Development Document
TDS	Total dissolved solids
TEC	Threshold effect concentration
TN	Total nitrogen
TP	Total phosphorus
TRI	Toxics Release Inventory
TSD	Technical support document
TSS	Total suspended solids
TTHM	Total trihalomethanes
TWTP	Total willingness-to-pay
U.S. FWS	United States Fish and Wildlife Service
USGS	United States Geological Survey
VIP	Voluntary Incentive Program
VOC	Volatile organic compounds
VSL	Value of a statistical life
WBD	Watershed Boundary Dataset
WQ	Water quality
WQI	Water quality index

WQI-BL	Baseline water quality index
WQI-PC	Post-technology implementation water quality index
WQL	Water quality ladder
WTP	Willingness-to-pay

Executive Summary

The U.S. Environmental Protection Agency (EPA) is finalizing revisions to the technology-based effluent limitations guidelines and standards (ELGs) for the steam electric power generating point source category, 40 Code of Federal Regulations (CFR) part 423, which EPA proposed in November 2019 (84 FR 64620). The final rule revises certain best available technology economically achievable (BAT) effluent limitations and pretreatment standards for existing sources (PSES) for two wastestreams: flue gas desulfurization (FGD) wastewater and bottom ash (BA) transport water.

Regulatory Options

EPA presents four main regulatory options, summarized in Table ES-1. The four main regulatory options analyzed at proposal (1, 2, 3, and 4), the details of which were discussed in the proposed rule (84 FR 64620), correspond generally to regulatory options D, A, B, and C here, but do contain differences as detailed in the preamble. The availability and achievability of technologies with better pollutant removals, as well as the general lack of public comments in support for proposed regulatory Option 1, led EPA to focus updates to the Agency's analysis on the remaining three regulatory options. EPA did not update the analyses for regulatory Option D, but rather retained the results of the proposed rule analyses for this option (see the 2019 Benefits and Costs Analysis [BCA; U.S. EPA, 2019a]).

The baseline for the benefit and social cost analyses reflects ELG requirements in absence of this final EPA action.[1] As detailed in this report, EPA calculated the difference between the baseline and regulatory options A, B, and C to determine the net incremental effect (as positive or negative change) of the regulatory options.

EPA is finalizing Option A. For a description of Option A and other regulatory options EPA analyzed, see Table ES-1.

In general, the estimated incremental effects of the final rule, Option A, are small compared to baseline (see U.S. EPA, 2015a).

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[1] This includes the 2015 rule as well as the September 2017 postponement rule which delayed the earliest technology implementation date for the ELGs applicable to FGD wastewater and bottom ash transport water.

Table ES-1: Regulatory Options

Wastestream	Subcategory	Technology Basis for BAT/PSES Regulatory Options[a] 2015 Rule (Baseline)	Option D	Option A (Final Rule)	Option B	Option C
FGD Wastewater	NA (default unless in subcategory)[b]	Chemical Precipitation + HRTR Biological Treatment	Chemical Precipitation	Chemical Precipitation + LRTR Biological Treatment	Chemical Precipitation + LRTR Biological Treatment	Membrane Filtration
	High FGD Flow Facilities	NS	NS	Chemical Precipitation	NS	NS
	Low Utilization Boilers	NS	NS	Chemical Precipitation	NS	NS
	Boilers permanently ceasing the combustion of coal by 2028	NS	NS	Surface Impoundment	NS	NS
FGD Wastewater Voluntary Incentives Program (Direct Dischargers Only)		Evaporation	Membrane Filtration	Membrane Filtration	Membrane Filtration	NA
Bottom Ash Transport Water	NA (default unless in subcategory)[b]	Dry Handling / Closed Loop	High Recycle Rate Systems	High Recycle Rate Systems	High Recycle Rate Systems	High Recycle Rate Systems
	Low Utilization Boilers	NS	NS	Surface Impoundment + BMP Plan	NS	NS
	Boilers permanently ceasing the combustion of coal by 2028	NS	NS	Surface Impoundment	NS	NS

Abbreviations: BMP = Best Management Practice; HRTR = High Residence Time Reduction; LRTR = Low Residence Time Reduction; NS = Not subcategorized (default technology basis applies); NA = Not applicable

[a] See *Supplemental TDD* for a description of these technologies (U.S. EPA, 2020g).

[b] The table does not present existing subcategories included in the 2015 rule as EPA did not reopen the existing subcategorization of oil-fired units or units with a nameplate capacity of 50 MW or less.

Source: U.S. EPA Analysis, 2020

Benefits of Regulatory Options

EPA estimated the potential social welfare effects of the regulatory options and, where possible, quantified and monetized the benefits (see Chapters 3 through 11 for details of the methodology and results). Table ES-2 and Table ES-3 summarize the benefits that EPA quantified and monetized using 3 percent and 7 percent discounts, respectively. In the tables, positive values indicate improvements in social welfare, relative to the baseline, whereas negative values reflect forgone benefits of the regulatory options, *i.e.*, social welfare losses. In general, the estimated effects of implementing the regulatory options are comparable to those estimated at proposal (see U.S. EPA, 2019a), and are small compared to those estimated in 2015 (see U.S. EPA, 2015a).

EPA quantified but did not monetize other welfare effects of the regulatory options and discusses other effects only qualitatively. Chapter 2 presents additional information on these welfare effects.

Table ES-2: Summary of Total Annualized Benefits for Regulatory Options, Compared to Baseline, at 3 Percent (Millions of 2018$)

Benefit Category	*Option D*[a,b]	Option A[b] (Final Rule)	Option B[b]	Option C[b]
Human Health	***-$0.7***[c]	**-$0.3**	**-$0.3**	**-$0.1**
Changes in IQ losses in children from exposure to lead[d]	*<$0.0*	<$0.0	<$0.0	<$0.1
Changes in IQ losses in children from exposure to mercury	*-$0.3*	-$0.3	-$0.3	-$0.1
Ecological Conditions and Recreational Uses Changes	***-$12.5***	**-$15.3 to -$7.4**	**-$10.4 to -$5.5**	**-$9.9 to -$4.8**
Use and nonuse values for water quality changes[e]	*-$12.5*[i]	-$15.3 to -$7.4	-$10.4 to -$5.5	-$9.9 to -$4.8
Market and Productivity Effects[d]	***-$0.1***	**<$0.0**	**<$0.0**	**$0.0**
Changes in dredging costs[d]	*-$0.1*	<$0.0	<$0.0	<$0.0
Reduced water withdrawals[d]	*$0.0*	<$0.0	<$0.0	<$0.0
Air Quality-Related Effects	***$30***	**$14 to $51**	**$11 to $41**	**-$8.5 to -$2.4**
Climate change effects from changes in CO_2 emissions[f]	*-$30*	-$14	-$11	$2.3
Human health effects from changes in NO_X, SO_2, and $PM_{2.5}$ emissions[g]	*Not estimated*	$28 to $65	$23 to $52	-$11 to -$4.7
Total[g,h]	***-$43.3***	**-$1.7 to $43.3**	**$0.3 to $35.7**	**-$12.4 to -$13.4**

a. Option D corresponds to the proposed Option 1. EPA did not reanalyze this option for the final rule. All results shown for Option D are based on the 2019 analysis, as detailed in the 2019 BCA (U.S. EPA, 2019a). As such, the values do not reflect changes in the baseline, plant universe, and other analytical inputs for the analysis of Options A, B, and C.

b. Negative values represent forgone benefits and positive values represent realized benefits.

c. Total includes $0.4 million of benefits due to changes in bladder cancer risk from disinfection byproducts in drinking water as estimated for the 2019 proposed rule (U.S. EPA, 2019a).

d. "<$0.0" indicates that monetary values are greater than -$0.1 million but less than $0.0 million.

e. The range reflects the lower and upper bound willingness-to-pay estimates. See Chapter 6 for details.

f. Values for air-quality related effects are rounded to two significant figures. EPA estimated the air quality-related benefits for Option A. EPA extrapolated estimates of air quality-related benefits for Options B and C from the estimate for Option A that is based on IPM outputs. See Chapter 8 for details.

g. Values for air-quality related effects are rounded to two significant figures. The range reflects the lower and upper bound estimates of human health effects from changes in $PM_{2.5}$ and ozone levels. See Chapter 8 for details.

h. Values for individual benefit categories may not sum to the total due to independent rounding. Range is based on the low and high willingness to pay estimates and air quality-related effects.

i. Value reflects midpoint willingness-to-pay estimate. See 2019 BCA for details (U.S. EPA, 2019a).

Source: U.S. EPA Analysis, 2020

Table ES-3: Summary of Total Annualized Benefits for Regulatory Options, Compared to Baseline, at 7 Percent (Millions of 2018$)

Benefit Category	*Option D*[a,b]	Option A[b] (Final Rule)	Option B[b]	Option C[b]
Human Health	***-$0.3***[c]	**-$0.1**	**-$0.1**	**-$0.1**
Changes in IQ losses in children from exposure to lead[d]	*<$0.0*	<$0.0	<$0.0	<$0.0
Changes in IQ losses in children from exposure to mercury	*-$0.1*	-$0.1	-$0.1	-$0.1
Ecological Conditions and Recreational Uses Changes	***-$10.9***	**-$16.4 to -$8.0**	**-$12.0 to -$5.8**	**-$13.9 to -$6.7**
Use and nonuse values for water quality changes[e]	*-$10.9*[i]	-$16.4 to -$8.0	-$12.0 to -$5.8	-$13.9 to -$6.7
Market and Productivity Effects[d]	***-$0.1***	**<$0.0**	**<$0.0**	**<$0.0**
Changes in dredging costs[d]	*-$0.1*	<$0.0	<$0.0	<$0.0
Reduced water withdrawals[d]	*$0.0*	<$0.0	<$0.0	<$0.0
Air Quality-Related Effects	***-$4.8***	**$23 to $54**	**$19 to $44**	**$2.7 to $6.4**
Climate change effects from changes in CO_2 emissions[f]	*-$4.8*	-$2.3	-$1.9	-$0.27
Human health effects from changes in NO_X, SO_2, and $PM_{2.5}$ emissions[g]	*Not estimated*	$25 to $56	$21 to $46	$3.0 to $6.6
Total[g,h]	***-$16.0***	**$6.5 to $45.9**	**$6.9 to $38.1**	**-$11.3 to -$0.4**

a. Option D corresponds to the proposed Option 1. EPA did not reanalyze this option for the final rule. All results shown for Option D are based on the 2019 analysis, as detailed in the 2019 BCA (U.S. EPA, 2019a). As such, the values do not reflect changes in the baseline, plant universe, and other analytical inputs for the analysis of Options A, B, and C.

b. Negative values represent forgone benefits and positive values represent realized benefits.

c. Total includes $0.2 million of benefits due to changes in bladder cancer risk from disinfection byproducts in drinking water as estimated for the 2019 proposed rule (U.S. EPA, 2019a).

d. "<$0.0" indicates that monetary values are greater than -$0.1 million but less than $0.0 million.

e. The range reflects the lower and upper bound willingness-to-pay estimates. See Chapter 6 for details.

f. Values for air-quality related effects are rounded to two significant figures. EPA estimated the air quality-related benefits for Option A. EPA extrapolated estimates of air quality-related benefits for Options B and C from the estimate for Option A that is based on IPM outputs. See Chapter 8 for details.

g. Values for air-quality related effects are rounded to two significant figures. The range reflects the lower and upper bound estimates of human health effects from changes in $PM_{2.5}$ and ozone levels. See Chapter 8 for details.

h. Values for individual benefit categories may not sum to the total due to independent rounding. Range is based on the low and high willingness to pay estimates and air quality-related effects.

i. Value reflects midpoint willingness-to-pay estimate. See 2019 BCA for details (U.S. EPA, 2019a).

Source: U.S. EPA Analysis, 2020

Social Costs of Regulatory Options

Table ES-4 presents the incremental social costs attributable to the regulatory options, calculated as the difference between each option and the baseline. The regulatory options generally result in cost savings across regulatory options and discount rates, except for Option C which results in additional costs at the three percent discount rate. Chapter 12 describes the social cost analysis. The compliance costs of the regulatory options are detailed in the Regulatory Impact Analysis (RIA) (U.S. EPA, 2020d).

Comparison of Benefits and Social Costs of Regulatory Options

In accordance with the requirements of Executive Order 12866: *Regulatory Planning and Review* and Executive Order 13563: *Improving Regulation and Regulatory Review*, EPA compared the benefits and costs of each regulatory option. Table ES-5 presents the incremental monetized benefits and incremental social costs attributable to the regulatory options, calculated as the difference between each option and the baseline.

Table ES-4: Total Annualized Benefits and Social Costs by Regulatory Option and Discount Rate (Millions of 2018$)

Regulatory Option	Total Monetized Benefits[a]	Total Social Costs
3% Discount Rate		
Option D[b]	*-$43.3*	*-$130.6*
Option A (Final Rule)	-$1.7 to $43.3	-$127.1
Option B	$0.3 to $35.7	-$103.2
Option C	-$12.4 to -$13.4	$21.4
7% Discount Rate		
Option D[b]	*-$16.0*	*-$154.0*
Option A (Final Rule)	$6.5 to $45.9	-$153.4
Option B	$6.9 to $38.1	-$126.4
Option C	-$11.3 to -$0.4	-$18.2

a. EPA estimated the air quality-related benefits for Option A. EPA extrapolated estimates of air quality-related benefits for Options B and C from the estimate for Option A that is based on IPM outputs. The range of benefits reflects the lower and upper bound estimates of human health effects from changes in $PM_{2.5}$ and ozone levels. See Chapter 8 for details.

b. Option D corresponds to the proposed Option 1. EPA did not reanalyze this option for the final rule. All results shown for Option D are based on the 2019 analysis, as detailed in the 2019 BCA (U.S. EPA, 2019a). As such, the values do not reflect changes in the baseline, plant universe, and other analytical inputs for the analysis of Options A, B, and C.

Source: U.S. EPA Analysis, 2020.

1 Introduction

EPA is finalizing a regulation that revises the technology-based ELGs for the steam electric power generating point source category, 40 CFR part 423, which EPA proposed in November 2019 (84 FR 64620). The final rule revises certain effluent limitations based on BAT and pretreatment standards for existing sources for two wastestreams: FGD wastewater and bottom ash (BA) transport water.

This document presents an analysis of the benefits and social costs of the regulatory options, including the final rule option (Option A), and complements other analyses EPA conducted in support of the final rule, described in separate documents:

- *Supplemental Environmental Assessment for Revisions to the Effluent Guidelines and Standards for the Steam Electric Power Generating Point Source Category* (*Supplemental EA*; U.S. EPA, 2020f). The *Supplemental EA* summarizes the potential environmental and human health impacts that are estimated to result from implementation of the final rule.
- *Supplemental Technical Development Document for Revisions to the Effluent Guidelines and Standards for the Steam Electric Power Generating Point Source Category* (*Supplemental TDD*; U.S. EPA, 2020g). The *Supplemental TDD* summarizes the technical and engineering analyses supporting the final rule. The *Supplemental TDD* presents EPA's updated analyses supporting the revisions to limitations and standards applicable to discharges of FGD wastewater and bottom ash transport water. These updates include additional data collection that has occurred since the signature of the 2015 rule, updates to the industry (*e.g.*, retirements, updates to FGD treatment and bottom ash handling), cost methodologies, pollutant removal estimates, corresponding non-water quality environmental impacts associated with updated FGD and bottom ash methodologies, and explanations for the calculation of the effluent limitations and standards.
- *Regulatory Impact Analysis for Revisions to the Effluent Limitations Guidelines and Standards for the Steam Electric Power Generating Point Source Category* (*RIA*; U.S. EPA, 2020d). The RIA describes EPA's analysis of the costs and economic impacts of the regulatory options. This analysis provides the basis for social cost estimates presented in Chapter 12 of this document. The RIA also provides information pertinent to meeting several legislative and administrative requirements, including the Regulatory Flexibility Act of 1980 (as amended by the Small Business Regulatory Enforcement Fairness Act [SBREFA] of 1996), the Unfunded Mandates Reform Act of 1995, Executive Order 13211 on *Actions Concerning Regulations That Significantly Affect Energy Supply, Distribution, or Use*, and others.

The rest of this chapter discusses aspects of the regulatory options that are salient to EPA's analysis of the benefits and social costs of the final rule and summarizes key analytic inputs used throughout this document.

The analyses of the regulatory options are based on data generated or obtained in accordance with EPA's Quality Policy and Information Quality Guidelines. EPA's quality assurance (QA) and quality control (QC) activities for this rulemaking include the development, approval and implementation of Quality Assurance Project Plans for the use of environmental data generated or collected from all sampling and analyses, existing databases and literature searches, and for the development of any models which used environmental data. Unless otherwise stated within this document, the data used and associated data analyses were evaluated as described in these quality assurance documents to ensure they are of known and documented quality, meet EPA's requirements for objectivity, integrity and utility, and are appropriate for the intended use.

1.1 Steam Electric Power Plants

The ELGs for the Steam Electric Power Generating Point Source Category apply to a subset of the electric power industry, namely those plants "with discharges resulting from the operation of a generating unit by an establishment whose generation of electricity is the predominant source of revenue or principal reason for operation, and whose generation of electricity results primarily from a process utilizing fossil-type fuel (coal, oil, or gas), fuel derived from fossil fuel (*e.g.*, petroleum coke, synthesis gas), or nuclear fuel in conjunction with a thermal cycle employing the steam water system as the thermodynamic medium" (40 Code of Federal Regulations [CFR] 423.10).

As described in the *RIA*, of the 914 steam electric power plants in the universe identified by EPA, only those coal fired power plants that discharge bottom ash transport water or FGD wastewater may incur compliance costs under the final rule. See *Supplemental TDD* and *RIA* for details (U.S. EPA, 2020d; 2020g). In total, EPA estimated that 112 steam electric power plants generate the wastestreams subject to the final rule.

1.2 Baseline and Regulatory Options Analyzed

EPA presents four regulatory options (see Table 1-1). These options differ in the stringency of controls and applicability of these controls to generating units or plants based on generation capacity utilization, retirement or repowering status, and scrubber purge flow (see *Supplemental TDD* for a detailed discussion of the options and the associated treatment technology bases). Additionally, under Options A and B, steam electric power plants may elect to participate in the Voluntary Incentive Program (VIP) which requires them to meet more stringent limits for FGD wastewater in exchange for additional time to comply with those limits.

The baseline for this analysis reflects applicable requirements (in absence of the final rule). The baseline includes the 2015 rule (80 FR 67838) as well as the September, 2017 postponement rule (82 FR 43494) which postpones the earliest compliance date for the new more stringent BAT effluent limitations and PSES for FGD wastewater and bottom ash transport water in the 2015 rule. As discussed further in Section 2.2.2 of the *RIA*, the baseline for this analysis also includes the effects of the 2020 CCR Part A rule.[2]

The Agency estimated and presents in this report the water quality and other environmental effects of FDG wastewater and bottom ash transport water discharges under both the 2015 rule baseline and regulatory options A through D presented in Table 1-1.[3] The Agency calculated the difference between the baseline and

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[2] In the 2015 CCR rule RIA (U.S. EPA, 2014), EPA explicitly accounts for the baseline closure of all surface impoundments (including composite lined surface impoundments) at the end of their useful life (40 years). At the end of a surface impoundment's useful life, facilities are projected to face a decision between multiple replacement disposal alternatives. EPA modeled these alternatives and selected the least-cost alternative for each facility (see section 3.2.4.2 of the 2015 CCR RIA). Based on EPA's cost estimates, the Agency found that the least-cost alternative universally involved some form of converting away from disposal surface impoundments and incurring the costs of making a "wet-dry conversion."

In light of the changes from the USWAG and Waterkeeper mandates, the 2020 CCR Part A RIA revises cost estimates to reflect the new timing and number of surface impoundment closures and wet to dry conversions (U.S. EPA, 2020e). All unlined surface impoundments are now required by these court decisions to close. EPA estimated the increase in annualized costs as $40.5 million in the adjusted baseline costs in Section 2.5 of the CCR Part A RIA.

[3] As noted above, option D is presented in this report, but the option D analysis has not been updated since proposal.

the regulatory options to determine the net effect of the regulatory options. The changes attributable to the regulatory options are the difference between each option and the baseline.

Table 1-1: Regulatory Options

Wastestream	Subcategory	Technology Basis for BAT/PSES Regulatory Options[a]				
		2015 Rule (Baseline)	**Option D**	**Option A (Final Rule)**	**Option B**	**Option C**
FGD Wastewater	NA (default unless in subcategory)[b]	Chemical Precipitation + HRTR Biological Treatment	Chemical Precipitation	Chemical Precipitation + LRTR Biological Treatment	Chemical Precipitation + LRTR Biological Treatment	Membrane Filtration
	High FGD Flow Facilities	NS	NS	Chemical Precipitation	NS	NS
	Low Utilization Boilers	NS	NS	Chemical Precipitation	NS	NS
	Boilers permanently ceasing the combustion of coal by 2028	NS	NS	Surface Impoundment	NS	NS
FGD Wastewater Voluntary Incentives Program (Direct Dischargers Only)		Evaporation	Membrane Filtration	Membrane Filtration	Membrane Filtration	NA
Bottom Ash Transport Water	NA (default unless in subcategory)[b]	Dry Handling / Closed Loop	High Recycle Rate Systems	High Recycle Rate Systems	High Recycle Rate Systems	High Recycle Rate Systems
	Low Utilization Boilers	NS	NS	Surface Impoundment + BMP Plan	NS	NS
	Boilers permanently ceasing the combustion of coal by 2028	NS	NS	Surface Impoundment	NS	NS

Abbreviations: BMP = Best Management Practice; HRTR = High Residence Time Reduction; LRTR = Low Residence Time Reduction; NS = Not subcategorized (default technology basis applies); NA = Not applicable

a. See *Supplemental TDD* for a description of these technologies (U.S. EPA, 2020g).

b. The table does not present existing subcategories included in the 2015 rule as EPA did not reopen the existing subcategorization of oil-fired units or units with a nameplate capacity of 50 MW or less.

Source: U.S. EPA Analysis, 2020

1.3 Analytic Framework

The analytic framework of this benefit-cost analysis (BCA) includes basic components used consistently throughout the analysis of benefits and social costs[4] of the regulatory options:

1. All values are presented in 2018 dollars;
2. Future benefits and costs are discounted using rates of 3 percent and 7 percent back to 2020;
3. Benefits and costs are analyzed over a 27-year period (2021 to 2047);
4. Technology installation and the resulting pollutant loading changes occur at the end of the estimated wastewater treatment technology implementation year;
5. Benefits and costs are annualized;
6. Positive values represent an increase in benefits (improvements in environmental conditions or incremental social costs) compared to baseline, whereas negative values represent forgone benefits (or social cost savings) compared to the baseline; and
7. Future values account for annual U.S. population and income growth, unless noted otherwise.

These components are discussed in the sections below.

EPA's analysis of the regulatory options generally follows the methodology the Agency used previously to analyze the 2015 rule (see *Benefit and Cost Analysis for the Final Effluent Limitations Guidelines and Standards for the Steam Electric Power Generating Point Source Category* (U.S. EPA, 2015a) and 2019 proposed rule (see U.S. EPA, 2019a). In analyzing the regulatory options, however, EPA made several changes relative to the analysis of the 2019 proposal:

- EPA used revised inputs that reflect the costs and loads estimated for regulatory options A through C (see *Supplemental TDD* and *RIA* for details) and estimated loading reductions for two distinct periods during the overall period of analysis to account for transitional conditions when different plants are in the process of installing technologies to meet the requirements under the final rule.
- EPA updated the baseline industry information to incorporate changes in the universe and operational characteristics of steam electric power plants such as electricity generating unit retirements and fuel conversions since the analysis of the 2019 proposal. EPA also incorporated updated information on the technologies and other controls that plants employ. See the *Supplemental TDD* for details on the changes (U.S. EPA, 2020g).
- Finally, EPA made certain changes to the methodologies to be consistent with approaches used by the Agency for other rules and/or incorporate recent advances in environmental assessment, health risk, and resource valuation research.

These changes are described in the relevant sections of this document, and summarized in *Appendix A*.

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[4] Unless otherwise noted, costs represented in this document are social costs.

1.3.1 Constant Prices

This BCA applies a year 2018 constant price level to all future monetary values of benefits and costs. Some monetary values of benefits and costs are based on actual past market price data for goods or services, while others are based on other measures of values, such as household willingness-to-pay (WTP) surveys used to monetize ecological changes resulting from surface water quality changes. This BCA updates market and non-market prices using the Consumer Price Index (CPI), Gross Domestic Product (GDP) implicit price deflator, or Construction Cost Index (CCI).[5]

1.3.2 Discount Rate and Year

This BCA estimates the annualized value of future benefits using two discount rates: 3 percent and 7 percent. The 3 percent discount rate reflects society's valuation of differences in the timing of consumption; the 7 percent discount rate reflects the opportunity cost of capital to society. In Circular A-4, the Office of Management and Budget (OMB) recommends that 3 percent be used when a regulation affects private consumption, and 7 percent in evaluating a regulation that would mainly displace or alter the use of capital in the private sector (OMB, 2003; updated 2009). The same discount rates are used for both benefits and costs.

All future cost and benefit values are discounted back to 2020.[6]

1.3.3 Period of Analysis

Benefits are projected to begin accruing when each plant implements the control technologies needed to comply with any applicable BAT effluent limitations or pretreatment standards. As discussed in the *RIA* (in Chapter 3), for the purpose of the economic impact and benefit analysis, EPA generally estimates that plants will implement bottom ash transport water control technologies to meet the applicable rule limitations and standards as their permits are renewed over the period of 2021 through 2025. However, some regulatory options provide a longer period to meet FGD effluent limits. Under Options A and B, plants may implement FGD wastewater controls as late as 2028[7] and under Option C, plants have until 2028 to meet FGD wastewater controls based on the membrane technology.[8] This schedule reflects differing levels of controls that may be needed to meet limits under different options as compared to the baseline and recognizes that control technology implementation is likely to be staggered over time across the universe of steam electric power plants.

The period of analysis extends to 2047 to capture the estimated life of the compliance technology at any steam electric power plant (20 or more years), starting from the year of technology implementation, which can be as late as 2028.

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[5] To update the value of a Statistical Life (VSL), EPA used the GDP deflator and the elasticity of VSL with respect to income of 0.4, as recommended in EPA's Guidelines for preparing Economic Analysis (U.S. Environmental Protection Agency, 2010a). EPA used the GDP deflator to update the value of an IQ point, CPI to update the WTP for surface water quality improvements, cost of illness (COI) estimates, and the price of water purchase, and the CCI to update the cost of dredging navigational waterways and reservoirs.

[6] In its analysis of the 2015 rule, EPA presented benefits in 2013 dollars and discounted these benefits and costs to 2015 (see U.S. EPA, 2015a), whereas the analysis of the 2019 proposed rule and this analysis used 2018 dollars and discounted benefits and costs to 2020.

[7] The VIP program under Options A and B allows facilities to implement FGD controls as late as 2028. Plants that are not participating in the VIP program may implement FGD controls as late as 2025.

[8] Different dates may apply to subcategories of facilities as described in Section 3.2.1.

The different compliance years between options, wastestreams, and plants means that environmental changes may occur in a staggered fashion over the analysis period as plants implement control technologies to meet applicable limits under each option. To analyze environmental changes from the baseline and resulting benefits, EPA used the annual average of loadings or other environmental changes (*e.g.*, air emissions, water withdrawals) projected during two distinct periods (2021-2028 and 2029-2047) within the overall analysis period (2021-2047). Section 3.2 provides further details on the breakout of the analysis periods.

1.3.4 Timing of Technology Installation and Loading Reductions

For the purpose of estimating benefits and social costs, EPA estimates that plants meet revised applicable limitations and standards by the end of their estimated technology implementation year and that any resulting changes in loadings will be in effect at the start of the following year.

1.3.5 Annualization of future costs and benefits

Consistent with the timing of technology installation and loading reductions described above, EPA uses the following equation to annualize the future stream of costs and benefits:

Equation 1-1.

$$AV = \frac{r(PV)}{(1+r)[1-(1+r)^{-n}]}$$

Where AV is the annualized value, PV is the present value, r is the discount rate (3 percent or 7 percent), and n is the number of years (27 years).

1.3.6 Direction of Environmental Changes and Benefits

The technology bases or subcategorizations shown in Table 1-1 for some regulatory options yield effluent limitations and standards that may be less stringent than the baseline. This is true, for example, for discharges of pollutants in bottom ash transport water or for subcategories under which FGD effluent limitations and standards are based on chemical precipitation only. Additionally, the delayed compliance deadline for FGD limitations and standards under some options, such as the 2028 deadline for meeting FGD wastewater limitations and standards based on membrane filtration technology under Option C, prolongs the period when plants would continue to operate their existing systems and discharge at current levels. The combination of these factors means that some options can be expected to provide negative benefits (*i.e.*, disbenefits or forgone benefits) when compared to the baseline. This document uses the generic term “benefits” whether the changes are truly beneficial or are detrimental to society (reduce social welfare). The sign, positive or negative, communicates the direction of the effects. Under this convention, positive benefit values indicate improvements in social welfare under the option as compared to the baseline. This effect is typically in the opposite direction as the change in environmental effects. For example, lower effluent pollutant concentrations (negative changes) reduce the incidence of the health effects being quantified (negative changes) and avoid excess mortality resulting from the exposure (positive changes).

1.3.7 Population and Income Growth

To account for future population growth or decline, EPA used the U.S. Census Bureau population forecasts for the United States (U.S. Census Bureau, 2017). EPA used the growth projections for each year to adjust affected population estimates for future years (*i.e.,* from 2021 to 2047).

Because WTP is expected to increase as income increases, EPA accounted for income growth for estimating the value of avoided premature mortality based on the value of a statistical life (VSL) and WTP for water quality improvements. To develop adjustment factors for VSL, EPA first used income growth factors in the Environmental Benefits Mapping and Analysis Program—Community Edition (BenMAP-CE) database between 1990 and 2025 to estimate a linear regression model, which the Agency then used to extrapolate the income growth factors for years 2026-2047. EPA applied the projected income data along with the income elasticity for the respective models (VSL and meta-regression) to adjust the VSL and meta-analysis estimates of WTP for water quality changes in future years.[9, 10]

1.4 Organization of the Benefit and Cost Analysis Report

This BCA report presents EPA's analysis of the benefits of the regulatory options, assessment of the total social costs, and comparison of the social costs and monetized benefits.

The remainder of this report is organized as follows:

- Chapter 2 provides an overview of the main benefits expected to result from the implementation of the main regulatory options analyzed for the final rule.
- Chapter 3 describes EPA's estimates of the environmental changes resulting from the regulatory options, including water quality modeling that underlays estimates of several categories of benefits.
- Chapters 4 and 5 details the methods and results of EPA's analysis of human health benefits from changes in pollutant exposure via the drinking water and fish ingestion pathways, respectively.
- Chapter 6 discusses EPA's analysis of the nonmarket benefits of changes in surface water quality resulting from the regulatory options.
- Chapter 7 discusses EPA's analysis of changes in benefits to threatened and endangered (T&E) species.
- Chapter 8 describes EPA's analysis of benefits associated with changes in emissions of air pollutants associated with energy use, transportation, and the profile of electricity generation for the regulatory options.
- Chapter 9 discusses benefits arising from changes in water withdrawals.
- Chapter 10 describes benefits from changes in maintenance dredging of navigational channels and reservoirs.
- Chapter 11 summarizes monetized benefits across benefit categories.
- Chapter 12 summarizes the social costs of the regulatory options.

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[9] These extrapolated income elasticity factors were originally developed for EPA's COBRA tool. The latest public version is 4.0 released in June 2020 (https://www.epa.gov/statelocalenergy).

[10] There is a relatively strong consensus in economic literature that income elasticities of approximately "1" are appropriate for adjusting WTP for water quality improvements in future years (Johnston *et al.*, 2019; Tyllianakis & Skuras, 2016). Therefore, EPA used an income elasticity of "1" in this analysis.

- Chapter 13 addresses the requirements of Executive Orders that EPA is required to satisfy for the final rule, notably Executive Order (EO) 12866, which requires EPA to compare the benefits and social costs of its actions.
- Chapter 14 details EPA’s analysis of the distribution of benefits across socioeconomic groups to fulfill requirements under EO 12898 on *Federal Actions to Address Environmental Justice in Minority Populations and Low-Income Populations*.
- Chapter 15 provides references cited in the text.

Several appendices provide additional details on selected aspects of analyses described in the main text of the report.

2 Benefits Overview

This chapter provides an overview of the welfare effects to society resulting from changes in pollutant loadings due to implementation of the main regulatory options analyzed for the final rule. EPA expects the regulatory options to change discharge loads of various categories of pollutants when fully implemented. The categories of pollutants include conventional (such as suspended solids, biochemical oxygen demand (BOD), and oil and grease), priority (such as mercury [Hg], arsenic [As], and selenium [Se]), and non-conventional pollutants (such as total nitrogen [TN], total phosphorus [TP], chemical oxygen demand [COD] and total dissolved solids [TDS]).

Table 2-1 presents estimated annual pollutant loads under full implementation of the effluent limitations and standards for the baseline and the regulatory options. The *Supplemental TDD* provides further detail on the loading changes (U.S. EPA, 2020g). As described in Section 3.2, loadings during interim years before all plants meet the requirements under the final rule differ from these values.

Table 2-1: Estimated Annual Pollutant Loadings and Changes in Loadings for Baseline and Regulatory Options Under Technology Implementation

Regulatory Option	Estimated Total Industry Pollutant Loadings (pounds per year)	Estimated Changes[a] in Pollutant Loadings from Baseline (pounds per year)
Baseline	1,530,000,000	NA
Option D[b]	*1,680,000,000*	*13,400,000*
Option A (Final Rule)	1,530,000,000	-972,000
Option B	1,510,000,000	-14,700,000
Option C	15,600,000	-1,510,000,000

NA: Not applicable to the baseline

Note: Pollutant loadings and removals are rounded to three significant figures, so figures do not sum due to independent rounding. For example, estimated changes in pollutant loadings from baseline for Option A are calculated as 1,528,154,581 lb/yr – 1,529,126,625 lb/yr = -972,044 lb/yr which when rounded to three significant figures becomes 1 ,530,000,000 – 1,530,000,000 in this table but still results in -972,000 lb/yr. See *Supplemental TDD* (U.S. EPA, 2020g) and Document Control Number (DCN) SE08644 for details.

a. Negative values represent loading reductions and positive values represent loading increases, compared to the baseline.

b. Regulatory Option D reflects the population, methodology, and pollutant loadings for Option 1 in the 2019 proposed rule (see Section 6.4 of the 2019 *TDD* (U.S. EPA, 2019k). The values do not reflect changes in the baseline, plant universe, and other analytical inputs for the analysis of Options A, B, and C.

Source: U.S. EPA Analysis, 2020

As discussed in Section 1.3.4, some of the options may increase pollutant loadings for some plants, wastestreams, pollutants, or years, when compared to the baseline. Technology options resulting in an overall increase in pollutant loadings would result in forgone benefits to society while options resulting in loading reductions would result in realized benefits. Furthermore, whether a regulatory option increases or reduces loadings depends on the particular plant, pollutant, and timing of the comparison to baseline conditions. Section 3.2 discusses the temporal profile of pollutant loads in further detail.

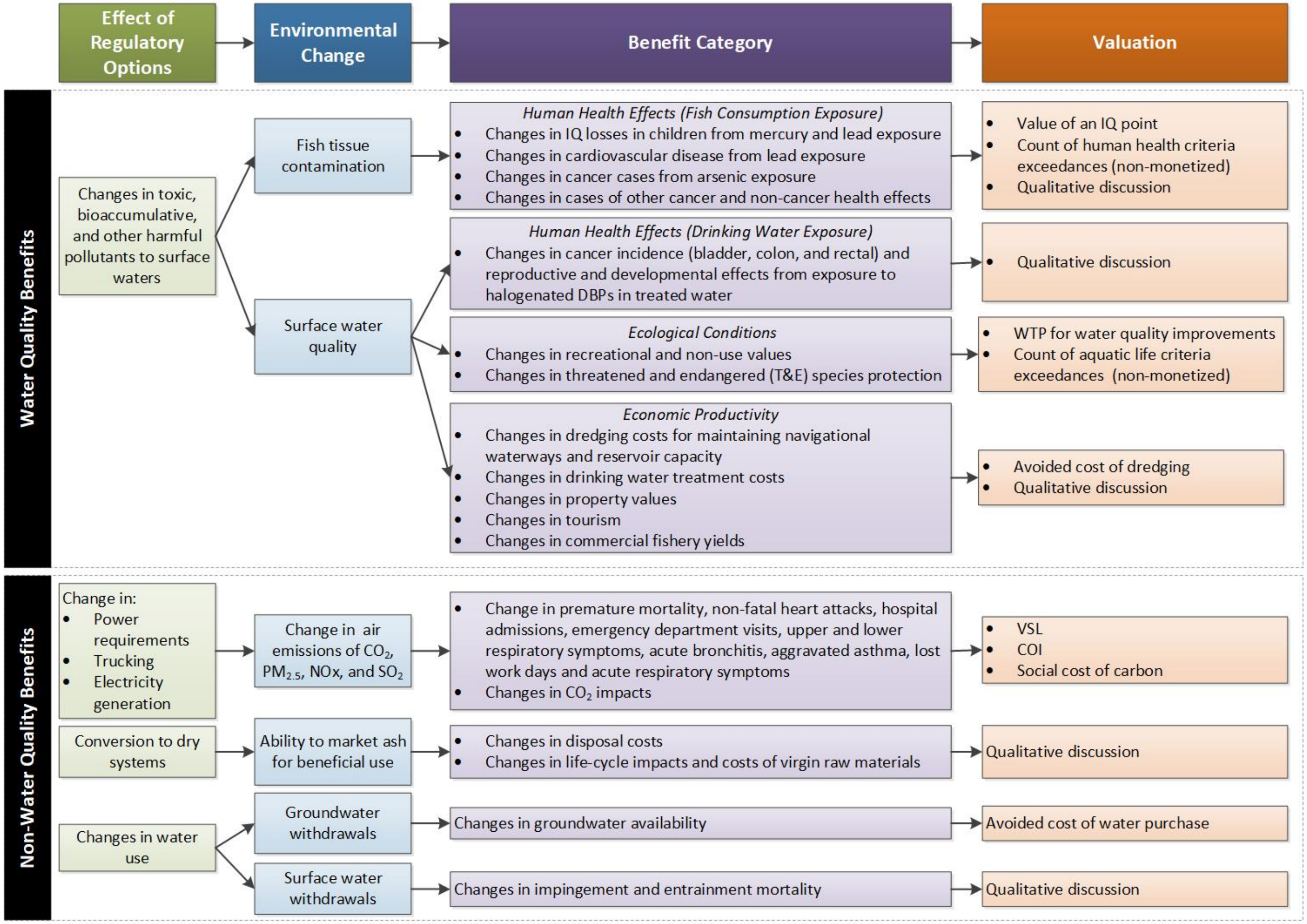
Changes estimated for Option A and Option B include effects of the VIP. Because participation in the VIP is voluntary, the number of plants that may participate in the program is uncertain. For the purposes of the costs and benefits analyses, EPA estimated VIP participants by comparing the discounted total annualized cost of chemical precipitation + LRTR biological treatment and membrane filtration for each plant, with the expectation that a plant owner would select the less costly of the two. The Agency estimated that eight steam electric power plants may choose to participate in the VIP under Option A and 14 plants may choose to participate in the VIP under Option B. The plants for which EPA estimates VIP may be the least-cost option vary in FGD wastewater flows, nameplate capacity, capacity utilization, and location. For these plants, EPA retained the membrane filtration costs for estimating economic impacts in the RIA and social costs in Chapter 12, and the membrane filtration loadings for the benefits analysis.

Effects of the regulatory options in comparison to the 2015 rule also include other effects of the implementation of control technologies or other changes in plant operations, such as changes in emissions of air pollutants (*e.g.*, carbon dioxide [CO_2], fine particulate matter [$PM_{2.5}$], nitrogen oxides [NO_X], and sulfur dioxide [SO_2]) which result in benefits to society in the form of changes in morbidity and mortality and CO_2 impacts on environmental quality and economic activities. Other effects include changes in water use, which provide benefits in the form of changes in the availability of surface water and groundwater.

This chapter also provides a brief discussion of the effects of pollutants found in bottom ash transport water and FGD wastewater addressed by the regulatory options on human health and ecosystem services, and a framework for understanding the benefits expected to be achieved by these options. For a more detailed description of steam electric wastewater pollutants, their fate, transport, and impacts on human health and environment, see the *Supplemental EA* (U.S. EPA, 2020f).

Figure 2-1 summarizes the potential effects of the regulatory options, the expected environmental changes, and categories of social welfare effects as well as EPA's approach to analyzing those welfare effects. EPA was not able to bring the same depth of analysis to all categories of social welfare effects because of imperfect understanding of the link between discharge changes or other environmental effects of the regulatory options and welfare effect categories, and how society values some of these effects. EPA was able to quantify and monetize some welfare effects, quantify but not monetize other welfare effects, and assess still other welfare effects only qualitatively. The remainder of this chapter provides a qualitative discussion of the social welfare effects applicable to this rule, including human health effects, ecological effects, economic productivity, and changes in air pollution, solid waste generation, and water withdrawals. Some estimates of the monetary value of social welfare changes presented in this document rely on models with a variety of limitations and uncertainties, as discussed in more detail in Chapters 3 through 10 for the relevant benefit categories.

Figure 2-1: Summary of Benefits Resulting from the Regulatory Options.



DBP = Disinfection byproducts; WTP = Willingness to Pay; VSL = Value of Statistical Life; COI = Cost of illness

Source: U.S. EPA Analysis, 2020.

2.1 Human Health Impacts Associated with Changes in Surface Water Quality

Pollutants present in steam electric power plant wastewater discharges can cause a variety of adverse human health effects. Chapter 3 describes the approach EPA used to estimate changes in pollutant levels in waters. More details on the fate, transport, and exposure risks of steam electric pollutants are provided in the EA (U.S. EPA, 2015b, 2020f).

Human health effects are typically analyzed by estimating the change in the expected number of adverse human health events in the exposed population resulting from changes in effluent discharges. While some health effects (*e.g.*, cancer) are relatively well understood and can be quantified in a benefits analysis, others are less well characterized and cannot be assessed with the same rigor, or at all.

The regulatory options affect human health risk by changing exposure to pollutants in water via two principal exposure pathways discussed below: (1) treated water sourced from surface waters affected by steam electric power plant discharges and (2) fish and shellfish taken from waterways affected by steam electric power plant discharges. The regulatory options also affect human health risk by changing air emissions of pollutants via shifts in the profile of electricity generation, changes in auxiliary electricity use, and transportation; these effects are discussed separately in Section 2.4.

2.1.1 Drinking Water

Pollutants discharged by steam electric power plants to surface waters may affect the quality of water used for public drinking supplies. People may then be exposed to harmful constituents in treated water through ingestion, as well as inhalation and dermal absorption (*e.g.*, showering, bathing). The pollutants may not be removed adequately during treatment at a drinking water treatment plant, or constituents found in steam electric power plant discharges may interact with drinking water treatment processes and contribute to the formation of disinfection byproducts (DBPs).

Public drinking water supplies are subject to legally enforceable maximum contaminant levels (MCLs) established by EPA (U.S. EPA, 2018b). As the term implies, an MCL for drinking water specifies the highest level of a contaminant that is allowed in drinking water. The MCL is based on the MCL Goal (MCLG), which is the level of a contaminant in drinking water below which there is no known or expected risk to human health. EPA sets the MCL as close to the MCLG as possible, with consideration for the best available treatment technologies and costs. Table 2-2 shows the MCL and MCLG for selected constituents or constituent derivatives of steam electric power plant effluent.

Table 2-2: Drinking Water Maximum Contaminant Levels and Goals for Selected Pollutants in Steam Electric FGD Wastewater or Bottom Ash Transport Water Discharges

Pollutant	MCL (mg/L)	MCLG (mg/L)
Antimony	0.006	0.006
Arsenic	0.01	0
Barium	2.0	2.0
Beryllium	0.004	0.004
Bromate	0.010	0
Cadmium	0.005	0.005
Chromium (total)	0.1	0.1
Copper[a]	1.3	1.3
Cyanide (free cyanide)	0.2	0.2
Lead[a]	0.015	0

Table 2-2: Drinking Water Maximum Contaminant Levels and Goals for Selected Pollutants in Steam Electric FGD Wastewater or Bottom Ash Transport Water Discharges

Pollutant	MCL (mg/L)	MCLG (mg/L)
Mercury	0.002	0.002
Nitrate-Nitrite as N	10 (Nitrate); 1 (Nitrite)	10 (Nitrate); 1 (Nitrite)
Selenium	0.05	0.05
Thallium	0.002	0.0005
Total trihalomethanes[b]	0.080	Not applicable
bromodichloromethane	Not applicable	0
bromoform	Not applicable	0
dibromochloromethane	Not applicable	0.06
chloroform	Not applicable	0.07

a. MCL value is based on action level.

b. Bromide, a constituent found in steam electric power plant effluent, is a precursor is a precursor for Total Trihalomethanes and three of its subcomponents. Additional trihalomethanes may also be formed in the presence of iodine, a constituent also found in steam electric power plant wastewater discharges.

Source: 40 CFR 141.53 as summarized in U.S. EPA (2018b): National Primary Drinking Water Regulation, EPA 816-F-09-004

Pursuant to MCLs, public drinking water supplies are tested and treated for pollutants that pose human health risks. For the purpose of analyzing the human health benefits of the regulatory options, EPA estimates that treated water meets applicable MCLs in the baseline. Table 2-2 shows that for arsenic, bromate, lead, and certain trihalomethanes, the MCLG is zero. For these pollutants and for those that have an MCL above the MCLG (thallium), there may be incremental benefits from reducing concentrations below the MCL.

EPA used a mass balance approach to estimate the changes in halogen (bromide and iodine) levels in surface waters downstream from steam electric power plant outfalls. Halogens can be precursors for halogenated disinfection byproduct formation in treated drinking water, including trihalomethanes addressed by the total trihalomethanes (TTHM) MCL. The occurrence of TTHM and other halogenated disinfection byproducts in downstream drinking water depends on a number of environmental factors and site-specific processes at drinking water treatment plants. There is evidence of linkages between adverse human health effects, including bladder cancer, and exposure to halogenated disinfection byproducts in drinking water. For additional information on these topics, see the *Supplemental EA* (U.S. EPA, 2020f). For the 2019 proposed rule, EPA quantitatively estimated the effect of changes in surface water bromide levels on drinking water TTHM levels and bladder cancer incidence in exposed populations. EPA also monetized associated changes in human mortality and morbidity. EPA received public comments that further evaluation of certain DBPs should be completed and that the analysis at proposal should be subject to peer review. The Agency acknowledges that further study in this area should be conducted, including peer review of the model used at proposal. EPA did not update this analysis for the final rule beyond updating the downstream surface water concentrations of bromide and iodine but will continue to evaluate the scientific data on the health impacts of disinfection byproducts.[11].

To the extent the proposed rule analysis accurately quantified human health effects, the final rule's quantitative benefits analysis may underestimate human health-related benefits.

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[11] Where information is available on actual or expected concentrations for particular DBPs, the human health impacts can be monetized for those specific DBPs as was done in the Stage 2 Disinfection Byproduct Rule.

To assess potential for changes in health risk from exposure to arsenic, lead, and thallium in drinking water, EPA estimated changes in pollutant levels in source waters downstream from steam electric power plants under each policy option. This analysis is discussed in Section 4.2. EPA did not quantify or monetize benefits from reduced exposure to arsenic, lead, and thallium via drinking water due to the very small concentration changes in source waters downstream from steam electric plants. EPA notes that lead found in supplied water is generally associated with the water distribution infrastructure rather than source water quality.

2.1.2 Fish Consumption

Recreational and subsistence fishers (and their household members) who consume fish caught in the reaches downstream of steam electric power plants may be affected by changes in pollutant concentrations in fish tissue. EPA analyzed the following direct measures of change in risk to human health from exposure to contaminated fish tissue:

1. Neurological effects to children ages 0 to 7 from exposure to lead;
2. Neurological effects to infants from in-utero exposure to mercury;
3. Incidence of skin cancer from exposure to arsenic[12]; and
4. Reduced risk of other cancer and non-cancer toxic effects.

The Agency evaluated changes in potential intellectual impairment, or intelligence quotient (IQ), resulting from changes in childhood and in-utero exposures to lead and mercury. The EPA also translated changes in the incidence of skin cancer into changes in the number of skin cancer cases.

For constituents with human health ambient water quality criteria, the change in the risk of other cancer and non-cancer toxic effects from fish consumption is addressed indirectly in EPA's assessment of changes in exceedances of these criteria (see Section 5.7*)*.

EPA used a cost-of-illness (COI) approach to estimate the value of changes in the incidence of skin cancer, which are generally non-fatal (see Section 5.5). The COI approach allows valuation of a particular type of non-fatal illness by placing monetary values on measures, such as lost productivity and the cost of health care and medications that can be monetized. Some health effects of changes in exposure to steam electric pollutants, such as neurological effects to children and infants exposed to lead and mercury, are measured based on avoided IQ losses. Changes in IQ cannot be valued based on WTP approaches because the available economic research provides little empirical data on society's WTP to avoid IQ losses. Instead, EPA calculated monetary values for changes in neurological and cognitive damages based on the impact of an additional IQ point on an individual's future earnings and the cost of compensatory education for children with learning disabilities. These estimates represent only one component of society's WTP to avoid adverse neurological effects and therefore produce a partial measure of the monetary value from changes in exposure to lead and mercury. Employed alone, these monetary values would underestimate society's WTP to avoid adverse neurological effects. See Sections 5.3 and 5.4 for applications of this method to valuing health effects in children and infants from changes in exposure to lead and mercury. Although EPA performed a screening analysis for the 2019 proposal, which indicated very small changes in cardiovascular disease mortality for the

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[12] EPA is currently revising its cancer assessment of arsenic to reflect new data on internal cancers including bladder and lung cancers associated with arsenic exposure via ingestion (U.S. EPA, 2010b). Because cancer slope factors for internal organs have not been finalized, the Agency did not consider these effects in the analysis of the final rule.

proposed rule options compared to those estimated in the analysis for the 2015 rule, EPA is not estimating avoided cardiovascular mortality that may result from the final rule. EPA acknowledges the scientific understanding of the relationship between lead exposure and cardiovascular mortality is evolving and scientific questions remain. (See also U.S. EPA, 2019c).

EPA received comments that it did not evaluate potential health impacts via the fish consumption pathway arising from changes in discharges of other steam electric pollutants, such as aluminum, boron, cadmium, hexavalent chromium, manganese, selenium, thallium, and zinc U.S. EPA, 2020f. Analyses of these health effects require data and information on the relationships between ingestion rate and potential adverse health effects and on the economic value of potential adverse health effects. Thus, due to data limitations and uncertainty in these quantitative relationships, for the final rule EPA did not quantify, nor was it able to monetize, changes in health effects associated with exposure to these pollutants. Despite numerous studies conducted by EPA and other researchers, dose-response functions are available for only a subset of health endpoints associated with steam electric wastewater pollutants. In addition, the available research does not always allow complete economic evaluation, even for quantifiable health effects. For example, sufficient data are not available to evaluate and monetize the following potential health effects from fish consumption: low birth weight and neonatal mortality from in-utero exposure to lead and other impacts to children from exposure to lead, such as decreased postnatal growth in children ages one to 16, delayed puberty, immunological effects, and decreased hearing and motor function (Cleveland *et al.*, 2008; NTP, 2012; U.S. EPA, 2013c; 2019c); effects to adults from exposure to lead such as cardiovascular diseases, decreased kidney function, reproductive effects, immunological effects, cancer and nervous system disorders (Aoki *et al.*, 2016; Chowdhury *et al.*, 2018; Lanphear *et al.*, 2018; NTP, 2012; U.S. EPA, 2013c; 2019c); neurological effects to children from exposure to mercury after birth (Grandjean *et al.*, 2014); effects to adults from exposure to mercury, including vision defects, hand-eye coordination, hearing loss, tremors, cerebellar changes, and others (Mergler *et al.*, 2007; Center for Disease Control and Prevention (CDC), 2009); and other cancer and non-cancer effects from exposure to other steam electric pollutants (*e.g.*, kidney, liver, and lung damage from exposure to cadmium, reproductive and developmental effects from exposure to arsenic, boron, and thallium, liver and blood effects from exposure to hexavalent chromium, and neurological effects from exposure to manganese) (California EPA, 2011; Oulhote *et al.*, 2014; Roels *et al.*, 2012; U.S. Department of Health and Human Services, 2012; U.S. EPA, 2020f).

EPA received comments that its analyses supporting the proposal didn’t fully consider cumulative or synergistic effects. Data and resource limitations preclude a full analysis cumulative or synergistic effects of pollutants that share the same toxicity mechanism, affect the same body organ or system, or result in the same health endpoint. For example, exposure to several pollutants discharged by steam electric plants (*i.e.*, lead, mercury, manganese, and aluminum) is associated with adverse neurological effects, in particular in fetuses and small children (Agency for Toxic Substances and Disease Registry (ATSDR), 2009; Grandjean *et al.*, 2014; NTP, 2012; Oulhote *et al.*, 2014; U.S. EPA, 2013c). A weight of evidence approach is typically used in qualitatively evaluating the cumulative effect of a chemical mixture. Cumulative effects often depend on exposure doses as well as potential threshold effects (ATSDR, 2004; 2009).

Due to these limitations, the total monetary value of changes in human health effects included in this analysis represent only a subset of the potential health benefits (or forgone benefits) that are expected to result from the regulatory options.

2.1.3 Complementary Measure of Human Health Impacts

EPA quantified but did not monetize changes in pollutant concentrations in excess of human health-based national recommended water quality criteria (NRWQC). This analysis provides a measure of the change in cancer and non-cancer health risk by comparing the number of receiving reaches exceeding health-based NRWQC for steam electric pollutants in the baseline to the number exceeding NRWQC under the regulatory options (Section 5.7).

Because the NRWQC in this analysis are set at levels to protect human health through ingestion of water and aquatic organisms, changes in the frequency at which human health-based NRWQC are exceeded could translate into changes in risk to human health. This analysis should be viewed as an indirect indicator of changes in risk to human health because it does not reflect the magnitude of human health risk changes or the population over which those changes would occur.

2.2 Ecological and Recreational Impacts Associated with Changes in Surface Water Quality

The composition of steam electric power plant wastewater depends on a variety of factors, such as fuel composition, air pollution control technologies, and wastewater management techniques. Wastewater often contains toxic pollutants such as aluminum, arsenic, boron, cadmium, chromium, copper, iron, lead, manganese, mercury, nickel, selenium, thallium, vanadium, molybdenum, and zinc (U.S. EPA, 2020f). Discharges of these pollutants to surface water can have a wide variety of environmental effects, including fish kills, reduction in the survival and growth of aquatic organisms, behavioral and physiological effects in wildlife, and degradation of aquatic habitat in the vicinity of steam electric power plant discharges (U.S. EPA, 2020f). The adverse effects associated with releases of steam electric pollutants depend on many factors such as the chemical-specific properties of the effluent, the mechanism, medium, and timing of releases, and site-specific environmental conditions.

The modeled changes in environmental impacts are quite small. Still, EPA expects the ecological impacts from the regulatory options could include habitat changes for fresh- and saltwater plants, invertebrates, fish, and amphibians, as well as terrestrial wildlife and birds that prey on aquatic organisms exposed to steam electric pollutants. The change in pollutant loadings has the potential to result in changes in ecosystem productivity in waterways and the health of resident species, including threatened and endangered (T&E) species. Loadings projected under the rule have the potential to impact the general health of fish and invertebrate populations, their propagation to waters, and fisheries for both commercial and recreational purposes. Changes in water quality also have the potential to impact recreational activities such as swimming, boating, fishing, and water skiing. Finally, the final rule has the potential to impact nonuse values (*e.g.*, option, existence, and bequest values) of the waters that receive steam electric power plant discharges.

EPA’s analysis is intended to isolate possible effects of the regulatory options and the final rule on aquatic ecosystems and organisms, including T&E species, however, it does not take into account the fact that the National Pollutant Discharge Elimination System (NPDES) permit for each steam electric power plant, like all NPDES permits, is required to have limits more stringent than the technology-based limits established by an ELG, wherever necessary to protect water quality standards. Because this analysis does not project where a permit will have more stringent limits than those required by the ELG, it may overestimate any negative impacts to aquatic ecosystems and T&E species, including impacts that will not be realized at all because the permits will be written to include limits as stringent as necessary to meet water quality standards as required by the Clean Water Act (CWA).

2.2.1 Changes in Surface Water Quality

The regulatory options may affect the value of ecosystem services provided by surface waters through changes in the habitats or ecosystems (aquatic and terrestrial) that receive steam electric power plant discharges. Society values changes in ecosystem services by a number of mechanisms, including increased frequency of use and improved quality of the habitat for recreational activities (*e.g.*, fishing, swimming, and boating). Individuals also value the protection of habitats and species that may reside in waters that receive FGD wastewater and bottom ash transport water discharges, even when those individuals do not use or anticipate future use of such waters for recreational or other purposes, resulting in nonuse values.

EPA quantified potential environmental impacts from the regulatory options by estimating in-waterway concentrations of bottom ash transport water and FGD wastewater pollutants and translating water quality estimates into a single numerical indicator, a water quality index (WQI). EPA used the estimated change in WQI as a quantitative estimate of ecological changes for this regulatory analysis. Section 3.4 of this report provides details on the parameters used in formulating the WQI and the WQI methodology and calculations. In addition to estimating changes using the WQI, EPA compared estimated pollutant concentrations to freshwater NRWQC for aquatic life (see Section 3.4.1.1). The *Supplemental EA* (U.S. EPA, 2020f) details comparisons of the estimated concentrations in immediate receiving and downstream reaches to the freshwater acute and chronic NRWQC for aquatic life for individual pollutants.

A variety of primary methods exist for estimating recreational use values, including both revealed and stated preference methods (Freeman III, 2003). Where appropriate data are available or can be collected, revealed preference methods can represent a preferred set of methods for estimating use values. Revealed preference methods use observed behavior to infer users' values for environmental goods and services. Examples of revealed preference methods include travel cost, hedonic pricing, and random utility (or site choice) models.

In contrast to direct use values, nonuse values are considered more difficult to estimate. Stated preference methods, or benefit transfer based on stated preference studies, are the generally accepted techniques for estimating these values (OMB, 2003; U.S. EPA, 2010a). Stated preference methods rely on carefully designed surveys, which either (1) ask people about their WTP for particular environmental improvements, such as increased protection of aquatic species or habitats with particular attributes, or (2) ask people to choose between competing hypothetical "packages" of environmental improvements and household cost (Bateman et al., 2006). In either case, values are estimated by statistical analysis of survey responses.

Although the use of primary research to estimate values is generally preferred because it affords the opportunity for the valuation questions to closely match the policy scenario, the realities of the regulatory process often dictate that benefit transfer is the only option for assessing certain types of non-market values (Rosenberger and Johnston, 2007). Benefit transfer is described as the "practice of taking and adapting value estimates from past research … and using them … to assess the value of a similar, but separate, change in a different resource" (V. K. Smith *et al.*, 2002, p. 134). It involves adapting research conducted for another purpose to estimate values within a particular policy context (Bergstrom & De Civita, 1999). EPA followed the same methodology used in analyzing the 2015 rule and 2019 proposal (U.S. EPA, 2015a) and relied on a benefit transfer approach based on an updated meta-analysis of surface water valuation studies to estimate the use and non-use benefits of improved surface water quality resulting from the final rule. The updates consisted of incorporating WTP estimates from more recent peer review studies into EPA's existing econometric model.[13] This analysis is presented in Chapter 6.

2.2.2 Impacts on Threatened and Endangered Species

For T&E species, even minor changes to reproductive rates and small mortality levels may represent a substantial portion of annual population growth. By changing the discharge of steam electric pollutants to aquatic habitats, the regulatory options have the potential to impact the survivability of some T&E species living in these habitats. These T&E species may have both use and nonuse values. However, given the protected nature of T&E species and the fact that use activities, such as fishing or hunting, generally constitute "take" which is illegal unless permitted, the majority of the economic value for T&E species comes from nonuse values.[14]

EPA quantified but did not monetize the potential effects of the regulatory options on T&E species. EPA constructed databases to determine which species have habitat ranges that intersect waters downstream from steam electric power plants. EPA then queried these databases to identify "affected areas" of those habitats where 1) receiving waters do not meet aquatic life-based NRWQC under the baseline conditions; and 2) receiving waters do meet aquatic life-based NRWQC under regulatory options, or vice versa. Because NRWQC are set at levels to protect aquatic organisms, reducing the frequency at which aquatic life-based NRWQC are exceeded should translate into reduced effects to T&E species and potential improvement in species populations. Conversely, increasing the frequency of exceedances could potentially impact T&E species. Therefore, to estimate the benefits of the regulatory options, EPA identified the waterbodies that overlap with T&E species habitat ranges that see changes in achievement of wildlife NRWQC as a consequence of the regulatory options and used these data as a proxy for benefits to T&E species.[15] This analysis and results are presented in Chapter 7.

EPA was unable to monetize the final rule's effects on T&E species due to challenges in quantifying the response of T&E populations to changes in water quality conditions. Although a relatively large number of economic studies have estimated WTP for T&E protection, these studies focused on estimating WTP to avoid species loss/extinction, increase in the probability of survival, or an increase in species population levels (Richardson & Loomis, 2009). These studies suggest that people attach economic value to protection of T&E species ranging from $10.4 per household per year (in 2018$) for avoiding loss of the striped shiner (a fish species) to $172 (in 2018$) for doubling salmon population levels.[16] In addition, T&E species may serve as a focus for eco-tourism and provide substantive economic benefit to local communities. For example, Solomon *et al.* (2004) estimate that manatee viewing provides a net benefit (tourism revenue minus the cost of manatee protection) of $12 – $13 million (in 2018$) per year for Citrus County, Florida.[17] EPA's analysis does not account for the potential for the NPDES permit issuance process to establish more stringent site-specific

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[13] See ICF (2020) for additional detail on updating the meta-analysis.

[14] The Federal Endangered Species Act (ESA) defines "take" to mean "to harass, harm, pursue, hunt, shoot, wound, kill, trap, capture, or collect, or to attempt to engage in any such conduct." 16 U.S. Code § 1532

[15] EPA is not required by Section 7(a)(2) of the Endangered Species Act to consult with the Fish and Wildlife Service and National Marine Fisheries Service prior to promulgating this technology-based rule (see Executive Summary) because the Agency lacks discretion to account for effects on species when issuing a technology-based rule under sections 301(b), 304(b), 306 and 307(b) of the CWA.

[16] Values adjusted from $8.32 and $138 per household per year (in 2006$), respectively, using the CPI.

[17] Range adjusted from $8.2 - $9 million (in 2001$), using the CPI.

controls to meet applicable water quality standards (*i.e.*, water quality-based effluent limits issued under Section 301(b)(1)(C)), relative to baseline. The analysis may therefore overestimate any potential negative impacts to T&E species and associated forgone benefits.

2.2.3 Changes in Sediment Contamination

Effluent discharges from steam electric power plants can also contaminate waterbody sediments. For example, sediment adsorption of arsenic, selenium, and other pollutants found in FGD wastewater and bottom ash transport water discharges can result in accumulation of contaminated sediment on stream and lake beds (Ruhl *et al.*, 2012), posing a particular threat to benthic (*i.e.*, bottom-dwelling) organisms. These pollutants can later be re-released into the water column and enter organisms at different trophic levels. Concentrations of selenium and other pollutants in fish tissue of organisms of lower trophic levels can bio-magnify through higher trophic levels, posing a threat to the food chain at large (Ruhl *et al.*, 2012).

In waters receiving direct discharges from steam electric power plants, EPA examined potential exposures of ecological receptors (*i.e.*, sediment biota) to pollutants in contaminated sediment. Benthic organisms can be affected by pollutant discharges such as mercury, nickel, selenium, and cadmium (U.S. EPA, 2015b; 2020f). The pollutants in steam electric power plant discharges may accumulate in living benthic organisms that obtain their food from sediments and pose a threat to both the organism and humans consuming the organism. As discussed in the *Supplemental EA*, EPA modeled sediment pollutant concentrations in immediate receiving waters and compared those concentrations to threshold effect concentrations (TECs) for sediment biota (U.S. EPA, 2020f). In 2015, EPA also evaluated potential risks to fish and waterfowl that feed on aquatic organisms with elevated selenium levels and found that steam electric power plant selenium discharges elevated the risk of adverse reproduction impacts among fish and mallards in immediate receiving waters (U.S. EPA, 2015b).

By changing discharges of pollutants to receiving reaches, the final rule may affect the contamination of waterbody sediments, thereby impacting benthic organisms and changing the probability that pollutants could later be released into the water column and affect surface water quality and the waterbody food chain. Due to data limitations, EPA did not quantify or monetize the associated benefits.

2.3 Economic Productivity

The economic productivity changes estimated to result from the regulatory options may include changes in beneficial use of coal ash and the resulting reduction in disposal costs. Other potential economic productivity effects may stem from changes in the quality of public drinking water supplies and irrigation water; changes in sediment deposition in reservoirs and navigational waterways; and changes in tourism, commercial fish harvests, and property values. Due to the small magnitude of the estimated changes in water quality (see Chapter 3 for details), only changes in sediment deposition in reservoirs and navigational waterways are quantified and monetized. Other benefit categories (*e.g.*, effects on drinking water treatment costs) are discussed qualitatively in the following sections.

2.3.1 Marketability of Coal Ash for Beneficial Use

The regulatory options may prompt certain plants to convert from wet handling of bottom ash to dry handling. This change could in turn allow plants to more readily market the coal combustion residuals (CCR) to beneficial uses. In particular, bottom ash can be used as a substitute for sand and gravel in fill applications. There are economic productivity benefits from plants avoiding certain costs associated with disposing of the ash as waste and from society or users of the ash avoiding the cost and life-cycle effects associated with the displaced virgin material. In the analysis of the 2015 rule, EPA quantified the benefits from increased dry handling of fly ash and bottom ash (see Chapter 10 in U.S. EPA, 2015c). That analysis showed that the economic value was greatest for fly ash used in concrete production, and smallest for fly ash or bottom ash used as fill material.

Among the regulatory options considered for the final rule, Options A, B, and C could affect fly ash to the extent facilities decide to encapsulate membrane filtration brine with fly ash that is currently beneficially used. Since EPA could not estimate with certainty which facilities might use fly ash for encapsulation versus an alternative brine management method (*e.g.*, deep well injection), this potential change in fly ash beneficial use was not quantified and represents an uncertainty in the analysis. With respect to bottom ash, EPA estimates that only Option A would affect the quantity of bottom ash handled wet when compared to the baseline, and for that option the estimated increase in bottom ash handled wet is small (246,871 tons per year at five plants). See the *Supplemental TDD* for details (U.S. EPA, 2020g). Given the uncertainties associated with changes in fly ash, the small changes in the quantity of bottom ash handled wet, and the uncertainty associated with projecting plant-specific changes in marketed bottom ash, EPA did not quantify this benefit category in the analysis of the final rule.

2.3.2 Water Supply and Use

The regulatory options are projected to change loadings of steam electric pollutants to surface waters by small amounts relative to baseline, and thus may have small effects on the uses of these waters for drinking water supply and agriculture.

2.3.2.1 Drinking Water Treatment Costs

The regulatory options have the potential to affect costs of drinking water treatment (*e.g.*, filtration and chemical treatment) by changing eutrophication levels and pollutant concentrations in source waters. Eutrophication is one of the main causes of taste and odor impairment in drinking water, which has a major negative impact on public perceptions of drinking water safety. Additional treatment to address foul tastes and odors can significantly increase the cost of public water supply.

The Agency conducted a screening-level assessment to evaluate the potential for changes in costs incurred by public drinking water systems and concluded that such changes, while they may exist, are likely to be negligible. The assessment involved identifying the pollutants for which treatment costs may vary depending on source water quality, estimating changes in downstream concentrations of these pollutants at the location of drinking water intakes, and determining whether modeled water quality changes have the potential to affect drinking water treatment costs. Based on this analysis, EPA determined that there are no drinking water systems drawing water at levels that exceed an MCL for metals and other toxics listed in Table 2-2 such as selenium and cyanide under either the baseline or the regulatory options (see Section 4.2 for details). EPA estimated no changes in MCL exceedances under the regulatory options. At many drinking water treatment facilities, treatment system operations do not generally respond to small incremental changes in source water quality for one pollutant or a small subset of pollutants. Furthermore, associated operations costs are not expected to change significantly due to small incremental changes in water quality. Accordingly, EPA did not conduct an analysis of cost changes in publicly operated treatment systems.

Potential effects of the estimated changes in the levels of halogens downstream from steam electric power plant outfalls on drinking water treatment costs are uncertain for several reasons including that there can be other environmental sources of halogens and existing treatment technologies in the majority of PWS are not designed to remove halogens from raw surface waters. Halogens found in source water can react during routine drinking water treatment to generate harmful DBPs at levels that vary with site-specific conditions (Good & VanBriesen, 2017, 2019; Regli *et al.*, 2015; U.S. EPA, 2016b). EPA estimated the costs of controlling DBP levels to the MCL in treated water as part of the Stage 2 Disinfectants and Disinfection Byproduct Rule (DBPR). These costs include treatment technology changes as well as non-treatment costs such as routine monitoring and operational evaluations. Public water systems (PWS) may adjust their operations to control DBP levels, such as changing disinfectant dosage, moving the chlorination point, or enhancing coagulation and softening. These changes carry “negligible costs” (U.S. EPA, 2005a, page 7-19). Where those low-cost changes are insufficient to meet the MCL, PWS may need to incur irreversible capital costs to upgrade their treatment process to use alternative disinfection technologies such as ozone, ultraviolet light, or chloride dioxide; switch to chloramines for residual disinfection; or add a pre-treatment stage to remove DBP precursors (*e.g.*, microfiltration, ultrafiltration, aeration, or increased chlorine levels and contact time). Some drinking water treatment facilities have already had to upgrade their treatment systems as a direct result of halogen discharges from steam electric power plants (*United States of America v. Duke Energy*, 2015; Rivin, 2015). However, not all treatment technologies remove sufficient organic matter to control DBP formation to required levels (Watson *et al.*, 2012). Thus, increased halogens levels in raw source water could translate into permanently higher drinking water treatment costs at some plants, in addition to posing increased human health risk. Conversely, reducing halogen levels in source waters can reduce the health risk, even where treatment changes have already occurred.[18] In some cases, operation and maintenance (O&M) costs may also be reduced. EPA did not have data on drinking water treatment technologies at potentially affected PWS or estimates of how costs for those technologies vary with changes in halogens concentrations in source water. Since cost data were insufficient, the Agency assessed only the changes in levels of halogens downstream from steam electric power plant outfalls and the number of people served by PWS with changes in halogen levels in their source waters (see Section 2.1.1 for a discussion of this benefit category and Chapter 4 for a discussion of the analysis).

2.3.2.2 Irrigation and Other Agricultural Uses

Irrigation accounts for 42 percent of the total U.S. freshwater withdrawals and approximately 80 percent of the Nation’s consumptive water use. Irrigated agriculture provides important contributions to the U.S. economy accounting for approximately 40 percent of the total farm sales (Hellerstein *et al.*, 2019). Pollutants in steam electric power plant discharges can affect the quality of water used for irrigation and livestock watering. Although elevated nutrient concentrations in irrigation water would not adversely affect its usefulness for plants, other steam electric pollutants, such as arsenic, mercury, lead, cadmium, and selenium have the potential to affect soil fertility and enter the food chain (National Research Council, 1993). Nutrients can increase eutrophication, however, promoting cyanobacteria blooms that can kill livestock and wildlife that drink the contaminated surface water. TDS can impair the utility of water for both irrigation and livestock use. EPA did not quantify or monetize effects of quality changes in agricultural water sources arising from the regulatory options due to data limitations and small estimated changes in water quality.

2.3.3 Reservoir Capacity

Reservoirs serve many functions, including storage of drinking and irrigation water supplies, flood control, hydropower supply, and recreation. Streams can carry sediment into reservoirs, where it can settle and cause buildup of sediment layers over time, reducing reservoir capacity (Graf *et al.*, 2010) and the useful life of reservoirs unless measures such as dredging are taken to reclaim capacity (Hargrove *et al.*, 2010; Miranda, 2017). EPA expects that changes in suspended solids discharges under the regulatory options could affect reservoir maintenance costs by changing the frequency or volume of dredging activity. Changes in sediment

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[18] Regli *et al.* (2015) estimated benefits of reducing bromide across various types of water treatment systems.

loads could result in a modest increase in dredging costs in reservoirs under all regulatory options. See Chapter 10 for details.

2.3.4 Sedimentation Changes in Navigational Waterways

Navigable waterways, including rivers, lakes, bays, shipping channels and harbors, are an integral part of the United States' transportation network. E. Clark et al., 1985E. Clark et al., 1985E. Clark et al., 1985E. Clark et al., 1985E. Clark et al., 1985E. Clark et al., 1985E. Clark et al., 1985Navigable channels are prone to reduced functionality due to sediment build-up, which can reduce the navigable depth and width of the waterway (Clark *et al.*, 1985; Marc Ribaudo & Johansson, 2006). For many navigable waters, periodic dredging is necessary to remove sediment and keep them passable. Dredging of navigable waterways can be costly.

EPA estimated that Option C would reduce sediment loadings to surface waters and reduce dredging of navigational waterways. EPA quantified and monetized these benefits based on the avoided cost for projected changes in future dredging volumes. Conversely, EPA estimated that small increases in sediment loads under Options A and B would result in a small increase in dredging costs in navigational waterways. Chapter 10 describes this analysis.

2.3.5 Commercial Fisheries

Pollutants in steam electric power plant discharges can reduce fish populations by inhibiting reproduction and survival of aquatic species. These changes may negatively affect commercial fishing industries as well as consumers of fish, shellfish, and fish and seafood products. Estuaries are particularly important breeding and nursery areas for commercial fish and shellfish species. In some cases, excessive pollutant loadings can lead to the closure of shellfish beds, thereby reducing shellfish harvests. Improved water quality due to reduced discharges of steam electric pollutants would enhance aquatic life habitat and, as a result, contribute to reproduction and survival of commercially harvested species and larger fish and shellfish harvests, which in turn could lead to an increase in producer and consumer surplus. Conversely, an increase in pollutant loadings could lead to negative impacts on fish and shellfish harvest.

EPA did not quantify or monetize impacts to commercial fisheries under the regulatory options. EPA estimated that six steam electric power plants discharge bottom ash transport water or FGD wastewater directly to the Great Lakes or to estuaries. Although estimated increases or decreases in annual average pollutant loads under the regulatory options may affect local fish populations and commercial harvest, the overall effects to commercial fisheries arising from the regulatory options are likely to be negligible. Most species of fish have numerous close substitutes. The literature suggests that when there are plentiful substitute fish products, numerous fishers, and a strong ex-vessel market, individual fishers are generally price takers. Therefore, the measure of consumer welfare (consumer surplus) is unlikely to change as a result of small changes in fish landings, such as those EPA expects under the regulatory options.

2.3.6 Tourism

Discharges of pollutants may also affect the tourism and recreation industries (*e.g.*, boat rentals, sales at local restaurants and hotels) and, as a result, local economies in the areas surrounding affected waters due to changes in recreational opportunities. The effects of water quality on tourism are likely to be highly localized. Moreover, since substitute tourism locations may be available, increased tourism in one location (*e.g.*, the vicinity of steam electric power plants) may lead to a reduction in tourism in other locations or vice versa. Due to the estimated small magnitude of water quality changes expected from the regulatory options (see Section 3.4 for details) and availability of substitute sites, the overall effects on tourism and, as a result, social welfare is likely to be negligible. Therefore, EPA did not quantify or monetize this benefit category.

2.3.7 Property Values

Discharges of pollutants may affect the aesthetic quality of water resources by changing pollutant discharges and thus altering water clarity, odor, and color in the receiving and downstream reaches. Technologies implemented by steam electric power plants to comply with the regulatory options remove nutrients and sediments to varying degrees and have varying effects on water eutrophication, algae production, and water turbidity, and other surface water characteristics. Several studies (*e.g.*, K.J. Boyle *et al.*, 1999; Leggett & Bockstael, 2000; Gibbs *et al.*, 2002; Bin & Czajkowski, 2013; Walsh *et al.*, 2011; Tuttle & Heintzelman, 2014; Netusil *et al.*, 2014; Liu *et al.*, 2017) suggest that both waterfront and non-waterfront properties are more desirable when located near unpolluted water. Therefore, the value of properties located in proximity to waters contaminated with steam electric pollutants may increase or decrease due to changes in discharges of bottom ash transport water or FGD wastewater.

Due to data limitations, EPA was not able to quantify or monetize the potential change in property values associated with the regulatory options. The magnitude of the potential change depends on many factors, including the number of housing units located in the vicinity of the affected waterbodies, community characteristics (*e.g.*, residential density) and housing stock (*e.g.*, single family or multiple family) and the effects of steam electric pollutants on the aesthetic quality of surface water. Given the small changes in the aesthetic quality of surface waters that may result from the small changes in pollutant concentrations under the regulatory options, EPA expects impacts of the final rule on property values to be small. In addition, there may be an overlap between shifts in property values and the estimated total WTP for surface water quality changes discussed in Section 2.2.1.

2.4 Changes in Air Pollution

The final rule is expected to affect air pollution through three main mechanisms: 1) changes in energy use by steam electric power plants to operate wastewater treatment, ash handling, and other systems needed to comply with the final rule; 2) changes in transportation-related emissions due to changes in trucking of CCR and other waste to on-site or off-site landfills; and 3) the change in the profile of electricity generation due to relatively higher cost to generate electricity at plants incurring compliance costs (or conversely, lower generation costs for plants incurring cost savings). The altered profile of generation can result in lower or higher air pollutant emissions due to differences in emission factors for coal or natural gas combustion, or nuclear or hydroelectric power generation.

Of the three mechanisms above, the change in the emissions profile of electricity generation is the only one that increases emissions under the final rule. As described in Chapter 5 of the *RIA*, EPA used the Integrated Planning Model (IPM®), a comprehensive electricity market optimization model that can evaluate impacts within the context of regional and national electricity markets, to analyze impacts of the final rule (*i.e.*, Option A).

Electricity market analyses using IPM indicate that, under the final rule, coal fired electric power generation may increase by 0.6 percent in 2030 and by 0.4 percent in 2035 and 2040, when compared to the baseline (*see* RIA; U.S. EPA, 2020d). These small changes in generation generally result in air emsission increases that are also relatively small. Changes in coal-based electricity generation as a result of the final rule are compensated by changes in generation using other fuels or energy sources, such as natural gas, nuclear power, solar, and wind power. The net changes in air emissions reflect the differences in emissions factors for these other fuels, as compared to coal-fueled generation. Overall for the three mechanisms (auxiliary services, transportation, and market-level generation), EPA estimates changes in CO_2, SO_2, and NO_X emissions as compared to the baseline. EPA also estimates changes in direct emissions of $PM_{2.5}$, PM_{10}, Hg, and hydrogen chloride (HCl) from electricity generating units.

CO_2 is the most prevalent of the greenhouse gases, which are air pollutants that EPA has determined endanger public health and welfare through their contribution to climate change. EPA used estimates of the domestic social cost of carbon (SC-CO_2) to monetize the benefits of changes in CO_2 emissions as a result of the final rule. The SC-CO2 is a metric that estimates the monetary value of projected impacts associated with marginal changes in CO_2 emissions in a given year. It includes a wide range of anticipated climate impacts, such as net changes in agricultural productivity and human health, property damage from increased flood risk, and changes in energy system costs, such as reduced costs for heating and increased costs for air conditioning. Chapter 8 details this analysis.

NO_X, and SO_2 are known precursors to $PM_{2.5}$, a criteria air pollutant that has been associated with a variety of adverse health effects, including premature mortality and hospitalization for cardiovascular and respiratory diseases (*e.g.*, asthma, chronic obstructive pulmonary disease [COPD], and shortness of breath). EPA quantified changes in direct $PM_{2.5}$ emissions and in emissions of $PM_{2.5}$ and ozone[19] precursors NO_X and SO_2 and assessed impacts of those emission changes on air quality changes across the country using the Comprehensive Air Quality Model with Extensions (CAMx) (Ramboll Environ International Corporation, 2016). This is the same modeling approach EPA used in analyses of the final Affordable Clean Energy (ACE) rule (U.S. EPA, 2019i) and of the "National Emission Standards for Hazardous Air Pollutants: Coal- and Oil-Fired Electric Utility Steam Generating Units – Subcategory of Certain Existing Electric Utility Steam Generating Units Firing Eastern Bituminous Coal Refuse for Emissions of Acid Gas Hazardous Air Pollutants" (85 FR 20838; U.S. EPA, 2020c). EPA then used spatial fields of baseline and post-compliance air pollutant concentrations as input to Benefits Mapping and Analysis Program—Community Edition (BenMAP-CE) to estimate incremental human health effects (including the potential for premature mortality and morbidity) from changes in ambient air pollutant concentrations (U.S. EPA, 2018a). Chapter 8 details this analysis.

The final rule may also affect air quality through changes in electricity generation units emissions of larger particulate matter (PM_{10}) and hazardous air pollutants (HAP) including mercury and hydrogen chloride. The health effects of mercury are detailed in the *Supplemental EA* (U.S. EPA, 2020f). Hydrogen chloride is a corrosive gas that can cause irritation of the mucous membranes of the nose, throat, and respiratory tract. For more information about the impacts of mercury and hydrogen chloride emissions, see the Final Mercury and Air Toxics Standards (MATS) for Power Plants, [20] including 2020 revisions to the 2012 *Coal- and Oil-Fired Electric Utility Steam Generating Units National Emission Standards for Hazardous Air Pollutants* (85 FR 31286).

In addition to health effects from air emissions, air pollution can create a haze that affects visibility. Reduced visibility could impact views in national parks by softening the textures, fading colors, and obscuring distant features and therefore reduce the value of recreational activities (*e.g.*, K. J. Boyle *et al.*, 2016; Pudoudyal *et al.*, 2013). A number of studies (*e.g.*, Bayer *et al.*, 2006; Beron *et al.*, 2001; Chay & Greenstone, 1998) also found that reduced air quality and visibility can negatively affect residential property values.

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[19] Emissions of nitrogen oxides (NOx) lead to formation of both ozone and $PM_{2.5}$ while SO_2 emissions lead to formation of $PM_{2.5}$ only.

[20] See https://www.epa.gov/mats/regulatory-actions-final-mercury-and-air-toxics-standards-mats-power-plants.

2.5 Changes in Water Withdrawals

The final rule may change water withdrawals associated with wet bottom ash transport and wet FGD scrubbers. In comparison to the baseline, these changes are estimated to be small. The regulatory options are expected to increase water withdrawals from surface waterbodies under Option A and Option B, and from aquifers under all regulatory options. Overall, the estimated increase in water withdrawal ranges from 1.4 billion gallons per year (3.94 million gallons per day) under Option A to 1.6 billion gallons per year (4.49 million gallons per day) under Option B (see *Supplemental TDD* for details, U.S. EPA, 2020g). EPA estimates that power plants would decrease water withdrawals by 3.6 billion gallons per year (9.93 million gallons per day) under Option C.

Increased water use from groundwater sources by steam electric power plants under the regulatory options could reduce availability of groundwater supplies for alternative uses. One power plant affected by the final rule relies on groundwater sources. EPA's analysis of potential forgone benefits associated with an increase in groundwater withdrawal are presented in Chapter 9.

A change in surface water intake would affect impingement and entrainment mortality. An overall increase in surface water withdrawal under Options A and B would increase impingement and entrainment mortality. Although the overall increase in water withdrawal is modest, the significance of local ecological impacts is uncertain and will depend on the overall health of the affected species population as well as species vulnerability to impingement and entrainment (*e.g.*, if water intakes affect a nursery habitat). A reduction in water withdrawal under Option C may benefit fish species affected by impingement and entrainment mortality. Due to data limitations and uncertainty, EPA did not quantify and monetize these benefits as part of this analysis.

2.6 Summary of Benefits Categories

Table 2-3 summarizes the potential social welfare effects of the regulatory options analyzed for the final rule and the level of analysis applied to each category. As indicated in the table, only a subset of potential effects can be quantified and monetized. The monetized welfare effects include changes in some human health risks, use and non-use values from changes in surface water quality, changes in costs for dredging reservoirs and navigational waterways, changes in air pollution, and changes in water withdrawals. Other welfare effect categories, including expected changes of pollutant concentrations in excess of human health-based NRWQC limits and changes in halogen levels in PWS source waters downstream from steam electric power plants, were quantified but not monetized. Finally, EPA was not able to quantify or monetize other welfare effects, including impacts to commercial fisheries or changes in the marketability of coal ash for beneficial use. EPA evaluated these effects qualitatively as discussed above in Sections 2.1 through 2.5.

Table 2-3: Estimated Welfare Effects of Changes in Pollutant Discharges from Steam Electric Power Plants

Category	Effect of Regulatory Options	Benefits Analysis		
		Quantified	Monetized	Methods (Report Chapter where Analysis is Detailed)
Human Health Benefits from Surface Water Quality Improvements				
Changes in halogen levels in drinking water treatment plant source waters	Changes in halogen levels in PWS source water	✓		Halogen concentrations in PWS source water (Chapter 4)

Table 2-3: Estimated Welfare Effects of Changes in Pollutant Discharges from Steam Electric Power Plants

Category	**Effect of Regulatory Options**	**Benefits Analysis**		
		Quantified	**Monetized**	**Methods (Report Chapter where Analysis is Detailed)**
Changes in human health effects (*e.g.*, bladder cancer) associated with halogenated DBP exposure via drinking water	Changes in exposure to halogenated DBPs in drinking water			Qualitative discussion (Chapter 2)
IQ losses to children ages 0 to 7	Changes in childhood exposure to lead from fish consumption	✓	✓	IQ point valuation (Chapter 5)
Need for specialized education	Changes in childhood exposure to lead from fish consumption	✓	✓	Avoided cost (Chapter 5)
Incidence of cardiovascular disease	Changes in exposure to lead from fish consumption			Qualitative discussion (Chapter 2)
IQ losses in infants	Changes in in-utero mercury exposure from maternal fish consumption	✓	✓	IQ point valuation (Chapter 5)
Incidence of cancer	Changes in exposure to arsenic from fish consumption	✓	✓	COI (Chapter 5); Qualitative discussion (Chapter 2)
Other adverse health effects (cancer and non-cancer)	Changes in exposure to toxic pollutants (lead, cadmium, thallium, etc.) via fish consumption or drinking water	✓		Human health criteria exceedances (Chapter 5); Qualitative discussion (Chapter 2)
Reduced adverse health effects	Changes in exposure to pollutants from recreational water uses			Qualitative discussion (Chapter 2)
Ecological Condition and Recreational Use Effects from Surface Water Quality Changes				
Aquatic and wildlife habitat[a]	Changes in ambient water quality in receiving reaches	✓	✓	Benefit transfer (Chapter 6); Qualitative discussion (Chapter 2)
Water-based recreation[a]	Changes in swimming, fishing, boating, and near-water activities from water quality changes			
Aesthetics[a]	Changes in aesthetics from shifts in water clarity, color, odor, including nearby site amenities for residing, working, and traveling			
Non-use values[a]	Changes in existence, option, and bequest values from improved ecosystem health			
Aquatic organisms and other wildlife[a]	Changes in risks to aquatic life from exposure to steam electric pollutants			
Protection of T&E species	Changes in T&E species habitat and potential effects on T&E species populations	✓		Habitat range intersecting with reaches with NRWQC exceedances (Chapter 7); Qualitative discussion (Chapter 2)
Sediment contamination	Changes in deposition of toxic pollutants to sediment			Qualitative discussion (Chapter 2)

Table 2-3: Estimated Welfare Effects of Changes in Pollutant Discharges from Steam Electric Power Plants

Category	Effect of Regulatory Options	Benefits Analysis		
		Quantified	**Monetized**	**Methods (Report Chapter where Analysis is Detailed)**
Market and Productivity Effects				
Dredging costs	Changes in costs for maintaining navigational waterways and reservoir capacity	✓	✓	Cost of dredging (Chapter 10) ; Qualitative discussion (Chapter 2)
Beneficial use of ash	Changes in disposal costs and avoided lifecycle impacts from displaced virgin material			Qualitative discussion (Chapter 2)
Water treatment costs for drinking water and irrigation and other agricultural uses	Changes in quality of source water used for drinking and irrigation and other agricultural uses			Qualitative discussion (Chapter 2)
Commercial fisheries	Changes in fisheries yield and harvest quality due to aquatic habitat changes			Qualitative discussion (Chapter 2)
Tourism industries	Changes in participation in water-based recreation			Qualitative discussion (Chapter 2)
Property values	Changes in property values from changes in water quality			Qualitative discussion (Chapter 2)
Air Quality-Related Effects				
Air emissions of PM$_{2.5}$, NO$_X$ and SO$_2$	Changes in mortality and morbidity from exposure to particulate matter (PM$_{2.5}$) emitted directly or linked to changes in NO$_X$ and SO$_2$ emissions (precursors to PM$_{2.5}$ and ozone)	✓	✓	VSL and COI (Chapter 8); Qualitative discussion (Chapter 2)
Air emissions of NO$_X$ and SO$_2$	Changes in ecosystem effects; visibility impairment; and human health effects from direct exposure to NO$_2$, SO$_2$, and hazardous air pollutants.			Qualitative discussion (Chapters 2 and 8)
Air emissions of CO$_2$	Changes in climate change effects	✓	✓	Social cost of carbon (SC-CO$_2$) (Chapter 8; Appendix I)
Changes in Water Withdrawal				
Groundwater withdrawals	Changes in availability of groundwater resources	✓	✓	Cost per gallon of water withdrawn (Chapter 9); Qualitative discussion (Chapter 2)
Surface water withdrawals	Changes in vulnerability to impingement and entrainment mortality			Qualitative discussion (Chapter 2)

a. These values are implicit in the total WTP for water quality improvements.

Source: U.S. EPA Analysis, 2020

3 Water Quality Effects of Regulatory Options

Changes in the quality of surface waters, aquatic habitats and ecological functions due to the final rule depend on a number of factors, including the operational characteristics of steam electric power plants, treatment technologies implemented to control pollutant levels, the timing of treatment technology implementation, and the hydrography of reaches receiving steam electric pollutant discharges, among others. This chapter describes the surface water quality changes projected under the regulatory options. EPA modeled water quality based on loadings estimated for the baseline and for each of the regulatory options (Options A, B, and C).[21] The differences in predicted concentrations between the baseline and option scenarios represent the changes attributable to the regulatory options. These changes inform the analysis of several of the benefits described in Chapter 2 and detailed in later chapters of this report.

The analyses use pollutant loading estimates detailed in the *Supplemental TDD* (U.S. EPA, 2020g) and expand upon the analysis of immediate receiving waters described in the *Supplemental EA* (U.S. EPA, 2020f) by estimating changes in both receiving and downstream reaches. The *Supplemental EA* provides additional information on the effects of steam electric power plant discharges on surface waters and how they may change under the regulatory options.

3.1 Waters Affected by Steam Electric Power Plant Discharges

EPA estimates the regulatory options potentially affect 112 steam electric power plants.[22] EPA used the United States Geological Survey (USGS) medium-resolution National Hydrography Dataset (NHD) (USGS, 2018) to represent and identify waters affected by steam electric power plant discharges, and used additional attributes provided in version 2 of the NHDPlus dataset (U.S. EPA, 2019f) to characterize these waters.

Of the total 112 plants represented in the analysis, EPA estimated that 102 have non-zero pollutant discharges under the baseline or the regulatory options. In the aggregate, these 102 plants with modeled bottom ash transport water or FGD wastewater discharge to 108 waterbodies (as categorized in NHDPlus), including lakes, rivers, and estuaries.[23] NHDPlus also provides the Strahler Stream Order[24] for each reach, where the order increases as one moves from headwaters (order 1) to downstream segments (orders 2-9). Table 3-1 summarizes the Strahler Stream Order for the 108 reaches receiving loadings from steam electric plants under the baseline or the regulatory options. Stream order is one of the factors considered in evaluating potential uses of reaches (*e.g.*, whether the reach is likely to be fishable), when estimating benefits of water quality changes.

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[21] For more details about Option D, see the 2019 *BCA* (U.S. EPA, 2019a).

[22] EPA analyzed a total of 112 plants that generate the wastestreams within the scope of the final rule. Not all 112 plants have costs and/or loads under the baseline or regulatory options. For example, of the 112 plants analyzed, 108 plants are estimated to incur technology implementation costs under the baseline and 75 plants are estimated to incur technology implementation costs under Option A (see the *Supplemental TDD* for details [U.S. EPA, 2020g]). The modeling scope is all 112 plants, but as discussed in this section, some plants have zero loads whereas others discharge to waters that lack a valid flow path (*e.g.*, Great Lakes and estuaries).

[23] One plant discharges waste streams to two different receiving waters and one reach receives discharges from two separate plants.

[24] Strahler Stream Order is a numerical measure of stream branching complexity. First order streams are the origin or headwaters of a flowline. The confluence of two first order streams forms a second order stream, the confluence of two second order streams forms a third order stream, and so on.

Table 3-1: Strahler Stream Order Designation for Reaches Receiving Steam Electric Power Plant Discharges

Stream Order	Number of Reaches
1	15
2	10
3	6
4	8
5	9
6	17
7	14
8	20
9	3
Not classified[a]	6
Total	**108**

a. Receiving reaches without a valid stream order include four reaches in the Great Lakes, one reach in Hillsborough Bay, and one reach in Washington state.

Receiving reaches that lack NHD classification for both waterbody area type and stream order generally correspond to reaches that do not have valid flow paths[25] for analysis of the fate and transport of steam electric power plant discharges (see Section 3.3). While six steam electric power plants discharge bottom ash transport water and/or FGD wastewater to tidal reaches or the Great Lakes,[26] EPA did not assess pollutant loadings and water quality changes associated with these waterbodies because of the lack of a defined flow path in NHDPlus, the complexity of flow patterns, and the relatively small changes in concentrations expected.[27] EPA did not quantify the water quality changes and resulting benefits (or forgone benefits) to these systems. Thus, the total number of plants for which EPA estimated downstream water quality changes is 96 (102 plants with nonzero pollutant discharges minus six plants discharging to the Great Lakes or tidal waterbodies).

3.2 Changes in Pollutant Loadings

EPA estimated post-technology implementation pollutant loadings for each plant under the baseline and the regulatory options. The *Supplemental TDD* details the methodology (U.S. EPA, 2020g). The sections below discuss the approach EPA used to develop a profile of loading changes over time under the baseline and each regulatory option and summarize the results.

3.2.1 Implementation Timing

Benefits analyses account for the temporal profile of environmental changes as the public values changes occurring in the future less than those that are more immediate (OMB, 2003). As described in the final rule, the regulatory options incorporate varying technology implementation deadlines for meeting the revised limits depending on the wastestream and technology basis, including providing more time to

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[25] In NHDPlus, the flow path represents the distance traveled as one moves downstream from the reach to the terminus of the stream network. An invalid flow path suggests that a reach is disconnected from the stream network.

[26] Four reaches, one of which receives non-zero discharges from two steam electric power plants, are located in the Great Lakes (three reaches along or near Lake Michigan and one reach along Lake Erie). One additional reach is located in Hillsborough Bay and is influenced by tidal processes.

[27] EPA looked at the changes in pollutant loadings and impacts to these systems in selected case studies as part of the analysis of the 2015 rule (see 2015 *EA* for details; U.S. EPA, 2015b).

plants that participate in the VIP under Options A and B to meet more stringent FGD wastewater effluent limits.

Table 3-2 summarizes the estimated technology implementation schedules for the baseline and the regulatory options. This implementation schedule means that plants may be installing wastewater treatment technologies in different years across the industry and potentially even within a given plant (*e.g.*, complying with bottom ash transport water requirements in 2021 and FGD wastewater requirements in 2028). This in turn can translate into variations in pollutant loads to waters over time.

To estimate the benefits of the regulatory options, EPA first developed a time profile of loadings for each scenario (*i.e.*, baseline and each regulatory option), electricity generating unit (EGU), wastestream, and pollutant that reflects the current loadings, the estimated loadings under the applicable technology basis, the estimated technology implementation year for the plant, and the timing of any retirements or repowerings. Specifically, EPA used current loadings starting in 2021 through the applicable technology implementation year, technology-based loadings for all years following the implementation year, and zero loadings following a unit's retirement or repowering.

EPA then used this year-explicit time profile to calculate the annual average loadings discharged by each plant for two distinct periods within the overall period of analysis of 2021 through 2047:

- Period 1, which extends from 2021 through 2028, when the universe of plants would transition from current treatment practices to practices that achieve the revised limits, and
- Period 2, which extends from 2029 through 2047 and is the post-transition period during which the full universe of plants is projected to employ treatment practices that achieve the revised limits.

The analysis accounts for each plant's technology implementation year(s) and for announced unit retirements or repowerings. Using average annual values for two distinct periods instead of a single average over the entire period of analysis improves the representation of rule implementation and enables EPA to better capture the transitional effects of the regulatory options, including the temporary increases in loadings relative to the 2015 rule baseline due to an extended status quo from delayed implementation of new requirements. While using an annual average does not show the differences between the baseline and regulatory options for individual years within Period 1, EPA considers that the average provides a reasonable measure of the transitional effects of the regulatory options given the categories of benefits that EPA is analyzing, which generally result from changes in multi-year processes.

As discussed in the *RIA* (U.S. EPA, 2020d), there is uncertainty in the exact timing of when individual steam electric power plants would be implementing technologies to meet the final rule or the other regulatory options. This benefits analysis uses the same plant- and wastestream-specific technology installation years used in the cost and economic impact analyses. To the extent that technologies are implemented earlier or later, the annualized loading values presented in this section may under- or overstate the annual loads during the analysis period.

Table 3-2: Implementation Schedule by Wastestream and Regulatory Option

Year(s)	Bottom Ash Transport Water					FGD Wastewater				
	Baseline	**Option D**	**Option A**	**Option B**	**Option C**	**Baseline**	**Option D**	**Option A**	**Option B**	**Option C**
2020	**Current**	Current	Current	Current	Current	**Current**	Current	Current	Current	Current
2021	**Transition**	Transition	Transition	Transition	Transition	**Transition**	Transition (non-VIP plants)	Transition (non-VIP plants)	Transition (non-VIP plants)	Current
2022	**Transition**	Transition	Transition	Transition	Transition	**Transition**	Transition (non-VIP plants)	Transition (non-VIP plants)	Transition (non-VIP plants)	Current
2023	**Transition**	Transition	Transition	Transition	Transition	**Transition**	Transition (non-VIP plants)	Transition (non-VIP plants)	Transition (non-VIP plants)	Current
2024	**Full Implementation**	Full Implementation	Transition[a]	Transition[a]	Transition[a]	**Full Implementation**	Transition (non-VIP plants)[a]	Transition (non-VIP plants)[a]	Transition (non-VIP plants)[a]	Transition[a]
2025	**Full Implementation**	Full Implementation	Transition[a]	Transition[a]	Transition[a]	**Full Implementation**	Transition (non-VIP plants)[a]	Transition (non-VIP plants)[a]	Transition (non-VIP plants)[a]	Transition[a]
2026	**Full Implementation**	Full Implementation	Full Implementation	Full Implementation	Full Implementation	**Full Implementation**	Interim Loads	Interim Loads	Interim Loads	Transition
2027	**Full Implementation**	Full Implementation	Full Implementation	Full Implementation	Full Implementation	**Full Implementation**	Interim Loads	Interim Loads	Interim Loads	Transition
2028	**Full Implementation**	Full Implementation	Full Implementation	Full Implementation	Full Implementation	**Full Implementation**	Transition (VIP plants)	Transition (VIP plants)	Transition (VIP plants)	Transition
2029-2047	**Full Implementation**	Full Implementation	Full Implementation	Full Implementation	Full Implementation	**Full Implementation**	Full Implementation	Full Implementation	Full Implementation	Full Implementation

a. Indirect dischargers must meet the revised PSES limits by the end of 2023.

Current = Current loadings

Transition = Some plants meet the revised limits, based on their permitting schedule (see Section 3.1.3 in the *RIA* (U.S. EPA, 2020d) for details on the modeled plant-specific technology implementation schedule). Aggregate loadings are lower than under Current conditions but greater than under the Full Implementation conditions.

Interim Loads = Non-VIP plants have reached the steady-state post-technology implementation loadings, but loadings for VIP plants are still at the Current level.

Full Implementation = All plants meet revised limits. Loadings are at their lowest steady-state post-technology implementation level.

Source: U.S. EPA Analysis, 2020

3.2.2 Results

Differences in the stringency of effluent limits and pretreatment standards and the timing of their applicability to steam electric power plants (and the resulting treatment technology implementation) mean that changes in pollutant loads between the regulatory options and the baseline vary over the period of analysis. Within the period of analysis, the years 2021-2028 represent a period of transition as plants implement treatment technologies to meet the revised limits under the baseline and regulatory options, whereas years 2029 through 2047 have steady state loadings that reflect implementation of technologies across all plants.[28]

Table 3-3 summarizes the average annual changes during Period 1 and Period 2 in FGD wastewater, bottom ash transport water, and total loads for selected pollutants that inform EPA's analysis of the benefits discussed in Chapters 4 through 7 and in Chapter 10. Negative values in the table indicate *reductions* in pollutant loadings under an option as compared to the baseline, whereas positive values indicate *increases* in pollutant loadings.

As shown in the table, total annual average pollutant loads increase under Options A and B across all pollutants during Period 1, whereas Option C is estimated to result in net reductions of total bromide, iodine, phosphorus and thallium loads during that same period, but net increases in other pollutants.

Under Options A, loadings of the pollutants in FGD wastewater generally decline in Period 2 as a result of plants participating in the VIP program, but bottom ash loadings increase. Under Option A, there are net estimated reductions in bromide, cadmium, iodine, and nickel loadings.

While not apparent from the total values, the direction of the changes for a particular pollutant is not necessarily uniform across all plants under a given option. For example, plants that participate in the VIP program under Options A and B may see reduced pollutant loadings in their FGD wastewater when compared to the baseline, whereas pollutant loads may increase for non-VIP plants implementing chemical precipitation with LRTR biological treatment control technologies as compared to baseline. Additionally, while Option C reduces total bromide loads through treatment of FGD wastewater, plants with only bottom ash transport water discharges may discharge greater loads under Option C compared to baseline. These differences will have varying impacts on benefit estimates depending on the location of the plants and their proximity to sensitive populations or environmental receptors.

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[28] This steady state reflects unit retirements and repowerings. EPA accounted for unit retirements and repowerings by zeroing out the loadings starting in the year following the change in status.

Table 3-3: Annual Average Changes in Total Pollutant Loading in Period 1 (2021-2028) and Period 2 (2029-2047) for Selected Pollutants in Steam Electric Power Plant Discharges, Compared to Baseline (lb/year)

Pollutant	Option A[a] (Final Rule)			Option B[a]			Option C[a]		
	FGD	Bottom Ash	Total[b]	FGD	Bottom Ash	Total[b]	FGD	Bottom Ash	Total[b]
Period 1 (2021-2028)									
Antimony	18	465	483	18	211	229	27	211	238
Arsenic	4	250	254	4	113	117	-69	113	44
Barium	346	2,851	3,197	346	1,293	1,639	-412	1,293	880
Beryllium	1	[c]	1	1	[c]	1	-14	[c]	-14
Boron	38,100	142,300	180,400	38,100	64,600	102,600	-3,306,600	64,600	-3,242,000
Bromide	36	137,000	137,000	36	62,000	62,000	-5,823,000	62,000	-5,761,000
Cadmium	230	19	249	230	9	239	1,085	9	1,094
Chromium	24	136	161	24	62	86	25	62	87
Copper	38	106	144	38	48	86	134	48	182
Cyanide	85	[c]	85	85	[c]	85	-13,840	[c]	-13,840
Iodine	3	[c]	3	3	[c]	3	-167,920	[c]	-167,920
Lead	3	279	282	3	127	129	-37	127	89
Manganese	171,400	4,100	175,500	171,400	1,859	173,300	664,200	1,859	666,100
Mercury	18	3	20	17	1	18	83	1	84
Nickel	1,887	468	2,355	1,854	212	2,067	9,182	212	9,394
TN	1,546,000	71,000	1,616,000	423,000	32,000	455,000	2,674,000	32,000	2,707,000
TP	2	5,945	5,947	2	2,693	2,696	-4,950	2,693	-2,260
Selenium	15,440	328	15,770	4,576	149	4,725	29,290	149	29,440
Thallium	8	30	39	8	14	22	-107	14	-94
TSS	38,530	358,190	396,720	38,530	162,380	200,910	100,220	162,380	262,600
Zinc	2,912	906	3,818	2,912	411	3,323	14,240	411	14,650
Period 2 (2029-2047)									
Antimony	-9	332	323	-10	198	188	-261	198	-64
Arsenic	-8	179	170	-9	106	97	-354	106	-248
Barium	-250	2,039	1,789	-271	1,212	941	-8,580	1,212	-7,370
Beryllium	-2	[c]	-2	-2	[c]	-2	-81	[c]	-81
Boron	-293,800	101,800	-192,100	-327,800	60,500	-267,200	-13,727,800	60,500	-13,667,200
Bromide	-2,951,000	98,000	-2,853,000	-2,954,000	58,000	-2,896,000	-23,828,000	58,000	-23,770,000
Cadmium	-53	14	-39	-54	8	-45	-302	8	-294
Chromium	-13	97	84	-14	58	44	-395	58	-337
Copper	-13	76	63	-13	45	32	-236	45	-191
Cyanide	85	[c]	85	85	[c]	85	-13,840	[c]	-13,840
Iodine	-116,540	[c]	-116,540	-116,760	[c]	-116,760	-684,730	[c]	-684,730
Lead	-5	200	195	-5	119	113	-206	119	-87
Manganese	-51,400	2,933	-48,400	-53,300	1,744	-51,500	-794,700	1,744	-793,000
Mercury	-2	2	0	-3	1	-2	-6	1	-5
Nickel	-352	335	-17	-391	199	-192	-765	199	-566
TN	1,246,000	51,000	1,297,000	-52,000	30,000	-22,000	-497,000	30,000	-467,000
TP	-406	4,250	3,844	-454	2,526	2,071	-19,480	2,526	-16,960
Selenium	12,030	235	12,270	-518	140	-378	-858	140	-718
Thallium	-14	22	8	-16	13	-3	-596	13	-584
TSS	-5,880	256,270	250,380	-5,880	152,200	146,320	-397,370	152,200	-245,170
Zinc	-627	648	20	-630	385	-245	-1,810	385	-1,420

Table 3-3: Annual Average Changes in Total Pollutant Loading in Period 1 (2021-2028) and Period 2 (2029-2047) for Selected Pollutants in Steam Electric Power Plant Discharges, Compared to Baseline (lb/year)

Pollutant	Option A[a] (Final Rule)			Option B[a]			Option C[a]		
	FGD	Bottom Ash	Total[b]	FGD	Bottom Ash	Total[b]	FGD	Bottom Ash	Total[b]

a. Negative values represent a reduction in pollutant loadings as compared to the baseline.

b. FGD and bottom ash loadings may not add up to the total due to independent rounding.

c. EPA did not estimate changes in beryllium, cyanide, and iodine loadings associated with bottom ash transport water.

TN = Nitrogen, total (as N); TP = Phosphorus, total (as P); TSS = Total suspended solids

Source: U.S. EPA Analysis, 2020.

3.3 Water Quality Downstream from Steam Electric Power Plants

EPA used the estimated annual average changes in total pollutant loadings for Periods 1 and 2 to estimate concentrations downstream from each plant. The methodology uses two main models to estimate downstream concentrations from each plant for each period:

- A dilution model to estimate pollutant concentrations downstream from the plants. The approach, which for the purpose of this analysis is referred to as the D-FATE model (Downstream Fate And Transport Equations), involves calculating concentrations in each downstream medium-resolution NHD reach using annual average Enhanced Runoff Method (EROM) flows from NHDPlus v2 and mass conservation principles.
- USGS's SPAtially Referenced Regressions On Watershed attributes (SPARROW) to estimate flow-weighted nutrient (TN and TP) and suspended sediment concentrations. The SPARROW models provide baseline and regulatory option concentrations of TN, TP, and suspended solids concentration (SSC). For this analysis, EPA used the most recent calibrated regional models published by the USGS (Ator, 2019; Hoos & Roland Ii, 2019; Robertson & Saad, 2019; Wise, 2019; Wise *et al.*, 2019). These models define the stream network using the same medium-resolution NHD reaches used in D-FATE.

The models represent only discharges to reaches represented in the NHD, which include the vast majority of plants within the scope of the rule (106 plants out of 112 plants within the scope of the rule). As discussed in Section 3.1, EPA omitted six steam electric power plants that discharge to the Great Lakes or to estuaries from this analysis.

In the D-FATE model, EPA used stream routing and flow attribute information from the medium-resolution NHDPlus v2 to track masses of pollutants from steam electric power plant discharges and other pollutant sources as they travel through the hydrographic network. For each point source discharger, the D-FATE model estimates pollutant concentrations for the receiving reach and all downstream reaches based on NHD mean annual flows. In-stream flows are kept constant (*i.e.*, discharges have no effect on flows). EPA notes that steam electric power plant discharges frequently constitute a return of flow withdrawn for plant use from the same surface water. In addition, FGD and BA wastewater discharges generally comprise a very small fraction of annual mean flows in the NHDPlus v2 dataset.[29]

Following the approach used in the analysis of the 2015 rule and 2019 proposal (U.S. EPA, 2015a, 2019a) to estimate pollutant concentrations, EPA included loadings from major dischargers (in addition to the steam electric power plants) that reported to the 2016 Toxics Release Inventory (TRI).[30] TRI data were available for a subset of toxics: arsenic, barium, chromium, copper, lead, manganese, mercury, nickel, selenium, thallium, and zinc. EPA summed reach-specific concentrations from TRI dischargers and concentration estimates resulting from steam electric power plant loadings to represent water quality impacts from multiple sources. The pollutant concentrations calculated in the D-FATE model are used to derive fish tissue concentrations used to analyze human health effects from consuming self-caught fish (see Chapter 5), analyze nonmarket benefits of water quality improvements (see Chapter 6), and assess potential impacts to T&E species whose habitat ranges intersect with waters affected by steam electric plant discharges (see Chapter 7).

3.4 Overall Water Quality Changes

Following the approach used in the analysis of the 2015 rule and 2019 proposal (U.S. EPA, 2015a, 2019a), EPA used a WQI to link water quality changes from reduced toxics, nutrient and sediment discharges to effects on human uses and support for aquatic and terrestrial species habitat. The WQI translates water quality measurements, gathered for multiple parameters (*e.g.*, dissolved oxygen [DO], nutrients) that are indicative of various aspects of water quality, into a single numerical indicator. The WQI ranges from 0 to 100 with low values indicating poor quality and high values indicating good water quality.

As detailed in U.S. EPA (2015a), the WQI includes seven parameters: DO, BOD, fecal coliform (FC), TN, TP, suspended solids, and one aggregate subindex for toxics. The pollutants considered in the aggregate subindex for toxics are those that are discharged by modeled steam electric power plants or 2016 TRI dischargers and that have chronic aquatic life-based NRWQC. Following the approach used for the 2019 proposal analysis, pollutants that meet these qualifications include arsenic, hexavalent chromium, copper, lead, manganese, mercury, nickel, selenium, and zinc. See the *Supplemental EA* for details on NRWQC (U.S. EPA, 2020f). The subindex curve for toxics assigns the lowest WQI value of 0 to waters where exceedances are observed for the *nine* toxics analyzed, and a maximum WQI value of 100 to waters where there are no exceedances. Intermediate values are distributed between 100 and 0 in proportion to the number of exceedances.

3.4.1 WQI Data Sources

To calculate the WQI, EPA used modeled NRWQC exceedances for toxics (using concentrations from D-FATE) and modeled concentrations for TN, TP, and SSC from the respective SPARROW regional models. Following the approach used for the 2019 proposal, the USGS National Water Information System (NWIS) provided concentration data from 2007-2017 for three parameters that are held constant between the baseline

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[29] Steam electric power plant FGD discharge rates are typically approximately 1 million gallons per day (MGD), whereas the annual mean stream flows in receiving waters average approximately 15,000 MGD.

[30] According to EPA TRI National Analysis, TRI releases to water reported in 2018 were approximately 1 percent higher, in the aggregate, than releases reported in 2016 (195.0 million pounds versus. 192.3 million pounds). See https://www.epa.gov/trinationalanalysis/water-releases for details.

and regulatory options: 1) fecal coliform, 2) dissolved oxygen, and 3) biochemical oxygen demand (see Section 3.4.1.2).[31]

3.4.1.1 Exceedances of Water Quality Standards and Criteria

For each regulatory option, EPA identified reaches that do not meet NRWQC for aquatic life in Periods 1 and 2.[32] Table 3-4 summarizes the number of reaches with estimated exceedances of NRWQC in the baseline and under the regulatory options.

Table 3-4: Estimated Exceedances of National Recommended Water Quality Criteria under the Baseline and Regulatory Options

Regulatory Option	Number of Reaches with at Least One NRWQC Exceedance	
	Chronic	Acute
Period 1 (2021-2028)		
Baseline	19	4
Option A (Final Rule)	22	4
Option B	22	4
Option C	23	4
Period 2 (2029-2047)		
Baseline	3	3
Option A (Final Rule)	0	0
Option B	0	0
Option C	0	0

Source: U.S. EPA Analysis, 2020

Refer to the *Supplemental EA* for additional discussion of comparisons of receiving and downstream water pollutant concentrations to acute and chronic aquatic NRWQC (U.S. EPA, 2020f).

3.4.1.2 Sources for Ambient Water Quality Data

Following the approach used for the 2019 proposal analysis, EPA used average monitoring values for fecal coliform, dissolved oxygen, and biochemical oxygen demand for 2007-2017 where available. Where more recent data were not available, EPA used the same averages as for the 2015 rule analysis. EPA used a successive average approach to assign average values for the three WQI parameters not explicitly modeled (*i.e.*, DO, BOD, fecal coliform). The approach, which adapts a common sequential averaging imputation technique, involves assigning the average of ambient concentrations for a given parameter within a hydrologic unit to reaches within the same hydrologic unit with missing data, and progressively expanding the

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[31] USGS's NWIS provides information on the occurrence, quantity, quality, distribution, and movement of surface and underground waters based on data collected at approximately 1.5 million sites in all 50 States, the District of Columbia, and U.S. territories. More information on NWIS can be found at http://waterdata.usgs.gov/nwis/.

[32] Aquatic life criteria are the highest concentration of pollutants in water that are not expected to pose a significant risk to the majority of species in a given environment. For most pollutants, aquatic NRWQC are more stringent than human health NRWQC and thus provide a more conservative estimate of potential water quality impairment. Chronic criteria are derived using longer term (7-day to greater than 28-day) toxicity tests if available, or an acute-to-chronic ratio procedure where the acute criteria is derived using short term (48-hour to 96-hour) toxicity tests (U.S. EPA, 2017a). More information on aquatic NRWQC can be found at https://www.epa.gov/wqc/national-recommended-water-quality-criteria-aquatic-life-criteria-table and in the *Supplemental EA* (U.S. EPA, 2020f).

geographical scope of the hydrologic unit (Hydrologic unit code (HUC)8, HUC6, HUC4, and HUC2) to fill in all missing data.[33] This approach is based on the assumption that reaches located in the same watershed generally share similar characteristics. Using this estimation approach, EPA compiled ambient water quality data and/or estimates for all analyzed NHD reaches. As discussed below, the values of the three WQI parameters not explicitly modeled are kept constant for the baseline and regulatory policy scenarios. This approach has not been peer reviewed, but it has been used by EPA for several prior rules and reviewed by the public during the associated comment periods.

The water quality analysis included a total of 16,169 medium-resolution NHD reaches that are potentially affected by steam electric power plants under the baseline. Of these 16,169 NHD reaches, EPA estimated concentrations for 15,159 reaches affected by non-zero loadings from steam electric power plants. Table 3-5 summarizes the data sources used to estimate baseline and regulatory option values by water quality parameter.

Table 3-5: Water Quality Data used in Calculating WQI for the Baseline and Regulatory Options

Parameter	Baseline	Regulatory Option
TN	Concentrations calculated using SPARROW (baseline run)	Concentrations calculated using SPARROW (regulatory option run)
TP	Concentrations calculated using SPARROW (baseline run)	Concentrations calculated using SPARROW (regulatory option run)
Suspended sediment	Concentrations calculated using SPARROW (baseline run)	Concentrations calculated using SPARROW (regulatory option run)
DO	Observed values averaged at the WBD watershed level	No change. Regulatory option value set equal to baseline value
BOD	Observed values averaged at the WBD watershed level	No change. Regulatory option value set equal to baseline value
Fecal Coliform	Observed values averaged at the WBD watershed level	No change. Regulatory option value set equal to baseline value
Toxics	Baseline exceedances calculated using D-FATE model	Regulatory option exceedances calculated using D-FATE model

WBD = Watershed Boundary Dataset. The WBD is a companion dataset to the NHD

Source: U.S. EPA Analysis, 2020.

3.4.2 WQI Calculation

EPA used the approach described in the BCA for the 2015 rule and 2019 proposal (U.S. EPA, 2015a, 2019a) to estimate WQI values for each reach under the baseline and each option, and used revised subindex curves for TN, TP, and SSC[34] that reflect data from the most current SPARROW regional models (Ator, 2019; Hoos

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[33] Hydrologic Unit Codes (HUCs) are cataloguing numbers that uniquely identify hydrologic features such as surface drainage basins. The HUCs consist of 8 to 14 digits, with each set of 2 digits giving more specific information about the hydrologic feature. The first pair of values designate the region (of which there are 21), the next pair the subregion (total of 222), the third pair the basin or cataloguing unit (total of 352), and the fourth pair the subbasin, or accounting unit (total of 2,262) (U.S. Geological Survey, 2007). Digits after the first eight offer more detailed information, but are not always available for all waters. In this discussion, a HUC level refers to a set of waters that have that number of HUC digits in common. For example, the HUC6 level includes all reaches for which the first six digits of their HUC are the same.

[34] The 2015 WQI includes a subindex for TSS. For this analysis, EPA developed a curve for SSC based on more recent SPARROW regional models which estimates SSC rather than TSS concentrations (Ator, 2019; Hoos & Roland Ii, 2019; Robertson & Saad, 2019; Wise, 2019; Wise *et al.*, 2019). This bypasses translation of SSC to TSS values and any associated uncertainty.

& Roland Ii, 2019; Robertson & Saad, 2019; Wise, 2019; Wise *et al.*, 2019). Implementing the WQI methodology involves three key steps: 1) obtaining water quality levels for each of seven parameters included in the WQI; 2) transforming parameter levels to subindex values expressed on a common scale; and 3) aggregating the individual parameter subindices to obtain an overall WQI value that reflects waterbody conditions across the seven parameters. These steps are repeated to calculate the WQI value for the baseline, and for each analyzed regulatory option. See details of the calculations in *Appendix B*, including the subindex curves used to transform levels of individual parameters. The scope of this analysis is the same as that for the analysis of nonmarket benefits of water quality improvements discussed in Chapter 6, which focuses on reaches within 300 km of a steam electric plant outfall.[35]

3.4.3 Baseline WQI

The WQI value can be related to suitability for potential uses. Vaughan (1986) developed a water quality ladder (WQL) that can be used to indicate whether water quality is suitable for various human uses (*i.e.*, boating, rough fishing, game fishing, swimming, and drinking without treatment). Vaughan identified "minimally acceptable parameter concentration levels" for each of the five potential uses. Vaughan used a scale of zero to 10 instead of the WQI scale of zero to 100 to classify water quality based on its suitability for potential uses. Therefore, the WQI value corresponding to a given water quality use classification equals the WQL value multiplied by 10.

Based on the estimated WQI value under the baseline scenario (WQI-BL), EPA categorized each of the 10,454 NHD reaches using five WQI ranges (WQI < 25, 25≤WQI<45, 45≤WQI<50, 50≤WQI<70, and 70≤WQI) (Table 3-6). WQI values of less than 25 indicate that water is not suitable for boating (the recreational use with the lowest associated WQI on the WQL), whereas WQI values greater than 70 indicate that waters are swimmable (the recreational use with the highest associated WQI on the WQL).[36]

Table 3-6: Estimated Percentage of Potentially Affected Reach Miles by WQI Classification: Baseline Scenario

Water Quality Classification	Baseline WQ	Number of Reaches	Percent of Affected Reaches	Number of Reach Miles	Percent of Affected Reach Miles
Period 1 (2021-2028)					
Unusable	WQI<25	0	0.0%	0	0.0%
Suitable for Boating	25≤WQI<45	218	2.1%	281	2.6%
Suitable for Rough Fishing	45≤WQI<50	472	4.5%	463	4.4%
Suitable for Game Fishing	50≤WQI<70	4,798	45.9%	4,762	44.9%
Suitable for Swimming	70≤WQI	4,966	47.5%	5,104	48.1%
Total		**10,454**	**100.0%**	**10,610**	**100.0%**
Period 2 (2029-2047)					
Unusable	WQI<25	0	0.0%	0	0.0%
Suitable for Boating	25≤WQI<45	213	2.0%	277	2.6%
Suitable for Rough Fishing	45≤WQI<50	443	4.2%	425	4.0%

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[35] There are an estimated 16,169 NHD reaches on the downstream flow path of steam electric plant outfalls, of which 11,369 NHD reaches are within 300 km of any outfall. A subset of these reaches lack valid annual average flow data to estimate pollutant concentrations, leaving a total of 10,454 NHD reaches with the data needed to estimate WQI.

[36] EPA did not separately categorize waters where the WQI was greater than or equal to 90 (drinkable water) because surface waters are generally treated before distribution for potable use. Pollutant specific impacts on drinking water are addressed separately in Chapter 4.

Table 3-6: Estimated Percentage of Potentially Affected Reach Miles by WQI Classification: Baseline Scenario

Water Quality Classification	Baseline WQ	Number of Reaches	Percent of Affected Reaches	Number of Reach Miles	Percent of Affected Reach Miles
Suitable for Game Fishing	50≤WQI<70	4,832	46.2%	4,803	45.3%
Suitable for Swimming	70≤WQI	4,966	47.5	5,104	48.1%
Total		**10,454**	**100.0%**	**10,610**	**100.0%**

Source: U.S. EPA Analysis, 2020

3.4.4 Estimated Changes in Water Quality (ΔWQI) from the Regulatory Options

To estimate the benefits of water quality improvements resulting from the regulatory options, EPA calculated the change in WQI for each analyzed regulatory option as compared to the baseline. This analysis was done for each reach and for each of the two Periods. As discussed in Section 3.3, EPA estimated changes in ambient concentrations of TN, TP and suspended solids using the USGS's SPARROW models and toxics concentrations using the D-FATE model. Although the regulatory options would also indirectly affect levels of other WQI parameters, such as BOD and DO, these other parameters were held constant in this analysis for all regulatory options, due to methodological and data limitations.

The difference in the WQI between baseline conditions and a given regulatory option (hereafter denoted as ΔWQI) is a measure of the change in water quality attributable to the regulatory option. Table 3-7 presents water quality change ranges for the analyzed regulatory options under each analysis period.

Table 3-7: Ranges of Estimated Water Quality Changes for Regulatory Options, Compared to Baseline

Options	Minimum ΔWQI[a]	Maximum ΔWQI	25th Percentile ΔWQI	Median ΔWQI	75th Percentile ΔWQI	ΔWQI Interquartile Range
Option D[b]	*-5.29*	*0.00*	*Not estimated*	*-1.02×10^{-3}*	*Not estimated*	*0.01*
Period 1 (2021-2028)						
Option A (Final Rule)	-5.78	0.00	-2.41×10^{-3}	-3.82×10^{-4}	-4.15×10^{-5}	2.37×10^{-3}
Option B	-5.78	0.00	-1.43×10^{-3}	-3.13×10^{-4}	-2.88×10^{-5}	1.40×10^{-3}
Option C	-10.34	1.42	-6.01×10^{-3}	-3.21×10^{-4}	-2.03×10^{-5}	5.99×10^{-3}
Period 2 (2029-2047)						
Option A (Final Rule)	-0.65	1.52	-6.36×10^{-4}	-8.05×10^{-5}	0.00	6.36×10^{-4}
Option B	-0.65	1.52	-5.41×10^{-4}	-6.77×10^{-5}	0.00	5.41×10^{-4}
Option C	-0.11	15.21	-2.63×10^{-5}	0.00	3.51×10^{-3}	3.53×10^{-3}

a. Negative changes in WQI values indicate degrading water quality and positive changes indicate improving water quality.

b. Option D corresponds to the proposed Option 1. EPA did not reanalyze this option for the final rule. All results shown for Option D are based on the 2019 analysis, as detailed in the 2019 BCA (U.S. EPA, 2019a). As such, the values do not reflect changes in the baseline, plant universe, and other analytical inputs for the analysis of Options A, B, and C. In the 2019 analysis, EPA calculated annual average changes over the entire period of analysis (2021-2047) instead of the two periods used for the final rule analysis.

Source: U.S. EPA Analysis, 2020

3.5 Limitations and Uncertainty

The methodologies and data used in the estimation of the environmental effects of the regulatory options involve limitations and uncertainties. Table 3-8 summarizes the limitations and uncertainties and indicates the direction of the potential bias. Uncertainties associated with some of the input data are covered in greater detail in other documents. Regarding the uncertainties associated with use of the NHDPlus attribute data, see the NHDPlus v2 documentation (U.S. EPA, 2019f). Regarding the uncertainties associated with estimated loads, see the *Supplemental TDD* (U.S. EPA, 2020g).

Table 3-8: Limitations and Uncertainties in Estimating Water Quality Effects of Regulatory Options

Uncertainty/Limitation	Effect on Water Quality Effects Estimation	Notes
Limited data are available to validate water quality concentrations estimated in D-FATE	Uncertain	The modeled concentrations reflect only a subset of pollutant sources (*e.g.*, steam electric power plant discharges and TRI releases) whereas monitoring data also reflect other sources such as bottom sediments, air deposition, and other point and non-point sources of pollution. EPA comparisons of D-FATE estimates to monitoring data available for selected locations and parameters (*e.g.*, bromide concentrations downstream of steam electric power plant discharges) confirmed that D-FATE provides reasonable values. Also refer to the 2015 *EA* for discussion of model validation for selected case studies (U.S. EPA, 2015b)
Steam electric power plant discharges have no effects on reach annual average flows	Overestimate	The degree of overestimation in the estimation of pollutant concentrations, if any, would be small given that steam electric power plant discharge flows tend to be very small as compared to flows in modeled receiving and downstream reaches.
Ambient water toxics concentrations are based only on loadings from steam electric power plants and other TRI discharges.	Uncertain	Concentration estimates do not account for background concentrations of these pollutants from other sources, such as legacy pollution in sediments, non-point sources, point sources that are not required to report to TRI, air deposition, etc. Not including other contributors to background toxics concentrations in the analysis is likely to result in understatement of baseline concentrations of these pollutants and therefore of NRWQC exceedances. The effect on WQI calculations is uncertain.
Annual loadings are estimated based on EPA's estimated plant-specific technology implementation years	Uncertain	To the extent that technologies are implemented earlier or later, the Period 1 annualized loading values presented in this section may under- or overstate the annual loads during the analysis period. The effect of this uncertainty is limited to Period 1 since loads reach a steady-state level by the technology implementation deadlines applicable to the regulatory options (*e.g.*, by the end of 2028)
Changes in WQI reflect only reductions in toxics, nutrient, and suspended solids concentrations.	Underestimate	The estimated changes in WQI reflect only water quality changes resulting directly from changes in toxics, nutrient and sediment concentrations. They do not include changes in other water quality parameters (*e.g.*, BOD, dissolved oxygen) that are part of the WQI and for which EPA used constant values. Because the omitted water quality parameters are also likely to respond to changes in pollutant loads (*e.g.*, dissolved oxygen levels respond to changes in nutrient levels), the analysis underestimates the water quality changes.

Table 3-8: Limitations and Uncertainties in Estimating Water Quality Effects of Regulatory Options

Uncertainty/Limitation	Effect on Water Quality Effects Estimation	Notes
EPA used regional averages of monitoring data from 2007-2017 for fecal coliform, dissolved oxygen, and biochemical oxygen demand, when location-specific data were not available. In cases where more recent data were not available, EPA used the same averages as used in the 2015 rule analysis (U.S. EPA, 2015a).	Uncertain	The monitoring values were averaged over progressively larger hydrologic units to fill in any missing data. As a result, WQI values may not reflect certain constituent fluctuations resulting from the various regulatory options and/or may be limited in their temporal and spatial relevance. Note that the analysis keeps these parameters constant under both the baseline and regulatory options. Modeled changes due to the regulatory options are not affected by this uncertainty.
Use of nonlinear subindex curves	Uncertain	The methodology used to translate suspended solids and nutrient concentrations into subindex scores (see Section 3.4.2 and Appendix B) employs nonlinear transformation curves. Water quality changes that fall outside of the sensitive part of the transformation curve (*i.e.*, above/below the upper/lower bounds, respectively) yield no change in the analysis and no benefits in the analysis described in Chapter 6.

4 Human Health Benefits from Changes in Pollutant Exposure via the Drinking Water Pathway

As described in Section 2.1, human health benefits deriving from changes in pollutant loadings to receiving waters include those associated with changes in exposure to pollutants via treated drinking water use and fish consumption. This chapter addresses the first exposure pathway: drinking water. Chapter 5 addresses the fish consumption pathway.

The small changes in pollutant loadings from the regulatory options relative to the 2015 analysis (U.S. EPA, 2015b) could affect human health by changing halogen and other pollutant discharges to surface waters and, as a result, pollutant concentrations in the reaches that serve as sources of drinking water. The *Supplemental EA* presents background information regarding the potential impacts of halogen discharges on drinking water quality and human health (U.S. EPA, 2020f). Section 4.1 presents EPA's analysis of the modeled changes in halogen concentrations in public drinking water systems' source waters. Section 4.2 summarizes potential impacts on source waters from changes in other pollutant discharges. Section 4.3 discusses uncertainty and limitations associated with the analysis presented in this chapter.

In general, EPA estimated small impacts on source waters under the final rule relative to the baseline, compared to those estimated in the 2015 rule (see U.S. EPA, 2015a).

4.1 Estimates of Changes in Halogen Concentrations in Source Water

For the final rule, EPA estimated the change in halogen levels in the source water for PWS that have intakes downstream from steam electric power plants.[37] Halogens such as bromide and iodine are precursors for halogenated disinfection byproduct formation in treated drinking water, including certain trihalomethanes addressed by the TTHM MCL. Higher halogen levels in PWS source waters have been associated with higher levels of halogenated DBPs in treated drinking water. The formation of DBPs varies with site-specific factors. *In vitro* toxicology studies with bacteria and mammalian cells have documented evidence of genotoxic (including mutagenic), cytotoxic, tumorigenic, and developmental toxicity properties of iodinated DBPs, but the available data are insufficient at this time to determine the extent of iodinated DBP's contribution to adverse human health effects from exposure to treated drinking water. Populations exposed to changes in halogenated disinfection byproduct levels in their drinking water under the regulatory options could experience changes in the incidence of adverse health effects. For additional information on these issues, see the *Supplemental EA* (U.S. EPA, 2020f).

In this section, the Agency presents the number of PWS with modeled changes in bromide and iodine concentration in their source water, the magnitude and direction of these changes, and the PWS service population estimated to experience a change in DBP exposure levels due to changes in source water bromide and iodine levels.

4.1.1 Bromide Bromide and Iodine Concentrations in Surface Water

As described in the *Supplemental TDD* (U.S. EPA, 2020g), EPA estimated steam electric power plant-level bromide and iodine loadings associated with bottom ash transport water and FGD wastewater for the baseline and the regulatory options. Total plant loadings are calculated as the sum of bottom ash transport water and

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[37] These analyses correspond to steps 1 and 2 of the methodology EPA used for the 2019 proposal (see Chapter 4 in U.S. EPA, 2019a)

FGD wastewater loadings under each scenario. Data on iodine is more limited and loading estimates are available for FGD wastewater. See Section 6 of the *Supplemental TDD* for a discussion of the uncertainties associated with iodine data generally and the resulting uncertainties propagated within this analysis. This chapter presents EPA's best estimate of changes in bromide and iodine loadings under each of the regulatory options.

EPA used the D-FATE model described in Section 3.3 to estimate in-stream bromide concentrations downstream from 102 steam electric power plants that EPA estimated have non-zero bromide loads (*i.e.*, discharge FGD wastewater and/or bottom ash transport water) under the baseline or regulatory options. EPA used the same approach to estimate in-stream iodine concentrations downstream from the subset of 61 plants that EPA estimated have non-zero iodine loads (*i.e.*, plants discharging FGD wastewater). EPA first estimated the annual average bromide and iodine loads in Period 1 and Period 2 (see Section 3.2.1). EPA then estimated concentrations in the receiving reach and each downstream reach, using conservation of mass principles, until the load reaches the network terminus (*e.g.*, Great Lake, estuary).[38] EPA summed individual contributions from all plants to estimate total in-stream concentrations under the baseline and the regulatory options. Finally, EPA estimated the change in bromide and iodine concentrations in each reach as the difference between each regulatory option and the baseline. This change is not dependent on bromide or iodine contributions from other sources (*e.g.*, receiving waterbody background levels).

The bromide and iodine loading estimates represent two independent scenarios that each assume the subset of plants using coal additives (30 plants) rely exclusively on either bromide-based- or iodine-based additives, respectively. The two scenarios would therefore not occur concurrently. For example, no plant using bromide additives at the level used in developing the bromide loadings estimate would simultaneously use iodine additives at the level used in developing the iodine loadings estimate (and vice versa). The two scenarios are therefore best interpreted as bounding cases that represent maximum potential discharges of either constituent. At this time, more coal-fired facilities use bromide-based rather than iodine-based additives (Tinuum Group LLC, 2020). However, information on the additive type used by individual facilities in this analysis is limited.

4.1.2 Changes in Bromide and Iodine Levels in Source Water

4.1.2.1 Affected Public Water Systems

For the final rule, EPA updated the universe of PWS potentially affected by steam electric plant discharges to reflect adjustments to the universe of plants projected to be subject to the rule and their associated downstream reaches. EPA also collected more recent information about the operating characteristics of the water systems (*e.g.*, population served, facility status, wholesale water purchases).

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[38] As discussed in Section 3.1, EPA did not estimate concentration changes in the Great Lakes or estuaries.

EPA's Safe Drinking Water Information System (SDWIS) database[39] provides the latitude and longitude of surface water facilities[40], including source water intakes for public drinking water treatment systems. To identify potentially affected PWS, the Agency georeferenced each permanent surface water facility associated with non-transient community water systems to the NHD medium-resolution stream network used in D-FATE.[41] *Appendix E* describes the methodology EPA used to identify the NHD water feature for each facility. The SDWIS database also includes information on PWS primary sources (*e.g.*, whether a PWS relies primarily on groundwater or surface water for their source water), operational status, and population served, among other attributes. For this analysis, EPA used the subset of facilities that identify surface water as their primary water source (specifically surface water intakes and reservoirs) and were categorized as "active" and "permanent" in SDWIS. This subset of facilities corresponds to PWS that are more likely to be affected by upstream bromide and/or iodine releases on an ongoing basis, as compared to other systems that may use surface water sources only sporadically. This approach identifies populations most likely to experience changes in long-term halogenated DBP exposures and associated health effects due to the regulatory options.

PWS can be either directly or indirectly affected by steam electric power plant discharges. Directly affected PWS are systems with surface water intakes drawing directly from reaches downstream from steam electric power plants discharging bromide or iodine.[42] Other PWS are indirectly affected because they purchase their source water from another PWS via a "consecutive connection" instead of withdrawing directly from a surface water or groundwater source. For these systems, SDWIS provides information on the PWS that supplies the purchased water. EPA used SDWIS data to identify PWS that may be indirectly affected by steam electric power plant discharges because they purchase water from a directly affected PWS. The total potentially exposed population consists of the people served by both directly and indirectly affected systems.

Table 4-1 summarizes the intakes, PWS, and populations potentially affected by steam electric power plant discharges. Sixteen PWS may be directly and indirectly affected. In this analysis, the average distance from the steam electric power plant discharge point to the drinking water treatment plant intake is approximately 286 miles and more than a quarter of the intakes are located within 50 miles of a steam electric power plant outfall. A subset of these PWS are downstream of iodine discharges, specifically 208 reaches have intakes used by 764 PWS serving a total of 25.8 million people.

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[39] EPA used intake locations as of January 2018 and PWS data as of April 2020, which reflects the first quarter report for 2020. Intake location data are protected from disclosure due to security concerns. SDWIS public data records are available from the Federal Reporting Services system at https://ofmpub.epa.gov/apex/sfdw/.

[40] Surface water facilities include any part of a PWS that aids in obtaining, treating, and distributing drinking water. Facilities in the SDWIS database may include groundwater wells, consecutive connections between buyer and seller PWS, pump stations, reservoirs, and intakes, among others.

[41] This analysis does not include intakes that draw from the Great Lakes or other water bodies not analyzed in the D-FATE model.

[42] To identify potentially affected PWS, EPA looked at all downstream reaches starting from the immediate reach receiving the steam electric power plant discharge to the reach identified as the terminus of the stream network.

Table 4-1: Estimated Reaches, Surface Water Intakes, Public Water Systems, and Populations Potentially Affected by Steam Electric Power Plant Discharges

PWS Impact Category	Number of Reaches with Drinking Water Intakes	Number of Intakes Downstream of Steam Electric Power Plants	Number of PWS	Total Population Served (Million People)
Direct[a]	255	370	272	20.3
Indirect	Not applicable	Not applicable	677	11.3
Total	**255**	**370**	**949**	**31.6**

a. Includes 16 systems with intakes downstream of steam electric power plant discharges and that purchase water from other systems with intakes downstream of steam electric power plant discharges.

Source: U.S. EPA analysis, 2020

4.1.2.2 System-Level Changes in Bromide and Iodine Concentrations in Source Water

EPA estimated the change in bromide and iodine concentrations in the source water for each PWS that could result from the regulatory options. In this discussion, the term "system" refers to PWS and their associated drinking water treatment operations, whereas the term "facility" refers to the intake that is drawing untreated water from a source reach for treatment at the PWS level.

To estimate changes in bromide and iodine concentrations at the PWS level, EPA obtained the number of active permanent surface water sources used by each PWS based on SDWIS data. SDWIS does not provide information on respective source flow contributions from surface water and groundwater facilities for a given PWS. For drinking water treatment systems that have both surface water and groundwater facilities, EPA assessed changes from surface water sources only. This approach is reasonable given that the analysis is limited to the PWS for which SDWIS identifies surface water as primary source.

For intakes located on reaches modeled in D-FATE, EPA calculated the reach-level change in bromide and iodine concentration as the difference between the regulatory option and the baseline conditions. Some PWS rely on a single intake facility for their source water supply. If the source water reach associated with this single intake is affected by steam electric power plant bromide or iodine discharges, the system-level changes in bromide or iodine concentration at the PWS would equal the estimated change in bromide or iodine concentration of the source water reach. Other PWS rely on multiple intake facilities that may be located along different source water reaches. System-level changes in bromide or iodine concentrations at these PWS are an average of the estimated changes in bromide or iodine concentrations associated with each source water reach. For any additional intakes not located on the modeled reaches and for intakes relying on groundwater sources, EPA estimated zero change in bromide or iodine concentration. Because SDWIS does not provide information on source flows contributed by intake facilities used by a given PWS, EPA calculated the system-level change in bromide or iodine concentration assuming each active permanent source facility contributes equally to the total volume of water treated by the PWS. For example, the PWS-level change in bromide concentration for a PWS with three intakes, of which one intake is directly affected by steam electric power plant discharges, is estimated as one third of the modeled reach concentration change ($[\Delta Br + 0 + 0]/3$).

EPA addressed water purchases similarly, but with the change in bromide or iodine concentration associated with the consecutive connection set equal to the PWS-level change estimated for the seller PWS instead of a reach-level change. For facilities affected only indirectly by steam electric power plant discharges, EPA assumed zero change in bromide and iodine concentrations for any other unaffected source facility associated with the buyer. EPA also assumed that each permanent source facility contributes an equal share of the total volume of water distributed by the buyer. For the 16 intakes classified as both directly and indirectly affected by steam electric power plant bromide and iodine discharges, EPA assessed the total change in bromide or iodine concentration as a blended average of the change in concentration from both directly-drawn and purchased water.

Table 4-2 summarizes the distribution of changes in bromide concentrations under the regulatory options for the two analysis periods. The direction of the changes depends on the Period, option, source water reach, and PWS but is generally consistent with the changes in bromide loadings associated with FGD and bottom ash transport wastewaters under each regulatory option (see Table 3-3). During Period 1, Options A and B show either increases or no changes in bromide concentrations for all source waters and PWS and Option C shows both increases and decreases in bromide concentrations across locations. During Period 2, all regulatory options show both estimated increases and decreases in bromide concentrations with both the magnitude and scope (the number of reaches, PWS, and population served) of the decreases larger than during Period 1.

Table 4-3 provides a similar summary of the distribution of changes in iodine concentrations under the regulatory options. As was the case for bromide, the direction of the changes is generally consistent with the changes in iodine loadings (see Table 3-3). However, because these changes arise only from FGD wastewater, they are more uniform during Period 2 across the options. Thus, during Period 1, Options A and B show an estimated increase in iodine concentrations and Option C shows both increases and decreases in iodine concentrations. During Period 2, the three options show decreases in iodine concentrations.

Table 4-2: Estimated Distribution of Changes in Source Water and PWS-Level Bromide Concentrations by Period and Regulatory Option, Compared to Baseline

ΔBr Range (µg/L)	Number of Source Water Reaches			Number of PWS[a]			Population Served by PWS		
	Positive[b] ΔBr	Negative[b] ΔBr	No ΔBr (ΔBr = 0)	Positive[b] ΔBr	Negative[b] ΔBr	No ΔBr (ΔBr = 0)	Positive[b] ΔBr	Negative[b] ΔBr	No ΔBr (ΔBr = 0)
Option D[c]									
0 to 10	*212*	*0*	*66*	*699*	*0*	*316*	*Not estimated*	*Not estimated*	*Not estimated*
10 to 30	*0*	*0*	*0*	*0*	*0*	*0*	*Not estimated*	*Not estimated*	*Not estimated*
30 to 50	*0*	*0*	*0*	*0*	*0*	*0*	*Not estimated*	*Not estimated*	*Not estimated*
50 to 75	*0*	*0*	*0*	*0*	*0*	*0*	*Not estimated*	*Not estimated*	*Not estimated*
>75	*0*	*0*	*0*	*0*	*0*	*0*	*Not estimated*	*Not estimated*	*Not estimated*
Period 1									
Option A (Final Rule)									
0 to 10	245	0	10	894	0	55	30,510,519	0	1,102,458
10 to 30	0	0	0	0	0	0	0	0	0
30 to 50	0	0	0	0	0	0	0	0	0
50 to 75	0	0	0	0	0	0	0	0	0
>75	0	0	0	0	0	0	0	0	0
Option B									
0 to 10	245	0	10	894	0	55	30,510,519	0	1,102,458
10 to 30	0	0	0	0	0	0	0	0	0
30 to 50	0	0	0	0	0	0	0	0	0
50 to 75	0	0	0	0	0	0	0	0	0
>75	0	0	0	0	0	0	0	0	0
Option C									
0 to 10	67	157	3	249	600	13	6,796,937	21,787,841	202,550
10 to 30	0	19	0	0	61	0	0	2,140,443	0
30 to 50	0	8	0	0	15	0	0	286,635	0
50 to 75	0	1	0	0	11	0	0	398,571	0
>75	0	0	0	0	0	0	0	0	0
Period 2									
Option A (Final Rule)									
0 to 10	174	60	13	568	279	58	23,258,818	6,314,975	1,088,640
10 to 30	0	7	0	0	41	0	0	803,727	0
30 to 50	0	0	0	0	0	0	0	0	0
50 to 75	0	0	0	0	0	0	0	0	0
>75	0	1	0	0	3	0	0	146,817	0

Table 4-2: Estimated Distribution of Changes in Source Water and PWS-Level Bromide Concentrations by Period and Regulatory Option, Compared to Baseline

ΔBr Range (μg/L)	Number of Source Water Reaches			Number of PWS[a]			Population Served by PWS		
	Positive[b] ΔBr	Negative[b] ΔBr	No ΔBr (ΔBr = 0)	Positive[b] ΔBr	Negative[b] ΔBr	No ΔBr (ΔBr = 0)	Positive[b] ΔBr	Negative[b] ΔBr	No ΔBr (ΔBr = 0)
Option B									
0 to 10	167	67	13	549	298	58	18,203,137	11,370,656	1,088,640
10 to 30	0	7	0	0	41	0	0	803,727	0
30 to 50	0	0	0	0	0	0	0	0	0
50 to 75	0	0	0	0	0	0	0	0	0
>75	0	1	0	0	3	0	0	146,817	0
Option C									
0 to 10	46	124	5	188	449	13	6,105,600	14,857,638	194,799
10 to 30	0	36	0	0	169	0	0	5,042,608	0
30 to 50	0	18	0	0	55	0	0	3,239,910	0
50 to 75	0	15	0	0	43	0	0	1,217,991	0
>75	0	11	0	0	32	0	0	954,431	0

a. Includes systems potentially directly and/or indirectly affected by steam electric power plant discharges.

b. Positive values indicate higher estimated bromide concentrations under the regulatory option as compared to the baseline, whereas negatives values indicate lower bromide concentrations under the regulatory option.

c. Option D corresponds to the proposed Option 1. EPA did not reanalyze this option for the final rule. All results shown for Option D are based on the 2019 analysis, as detailed in the 2019 BCA (U.S. EPA, 2019a). As such, the values do not reflect changes in the baseline, plant universe, and other analytical inputs for the analysis of Options A, B, and C. In the 2019 analysis, EPA calculated annual average changes over the entire period of analysis (2021-2047) instead of the two periods used for the final rule analysis.

Source: U.S. EPA Analysis, 2020.

Table 4-3: Estimated Distribution of Changes in Source Water and PWS-Level Iodine Concentrations by Period and Regulatory Option, Compared to Baseline

ΔI Range (μg/L)	Number of Source Water Reaches			Number of PWS[a]			Population Served by PWS		
	Positive[b] ΔI	Negative[b] ΔI	No ΔI (ΔI = 0)	Positive[b] ΔI	Negative[b] ΔI	No ΔI (ΔI = 0)	Positive[b] ΔI	Negative[b] ΔI	No ΔI (ΔI = 0)
Period 1									
Option A (Final Rule)									
0 to 0.3	17	0	191	49	0	715	3,307,761	0	22,458,258
0.3 to 0.6	0	0	0	0	0	0	0	0	0
0.6 to 0.9	0	0	0	0	0	0	0	0	0
0.9 to 1.2	0	0	0	0	0	0	0	0	0
>1.2	0	0	0	0	0	0	0	0	0
Option B									
0 to 0.3	17	0	191	49	0	715	3,307,761	0	22,458,258
0.3 to 0.6	0	0	0	0	0	0	0	0	0
0.6 to 0.9	0	0	0	0	0	0	0	0	0
0.9 to 1.2	0	0	0	0	0	0	0	0	0
>1.2	0	0	0	0	0	0	0	0	0
Option C									
0 to 0.3	9	157	14	30	598	47	442,035	21,335,359	710,494
0.3 to 0.6	0	21	0	0	52	0	0	1,814,351	0
0.6 to 0.9	0	2	0	0	7	0	0	176,180	0
0.9 to 1.2	0	3	0	0	19	0	0	995,383	0
>1.2	0	2	0	0	11	0	0	292,217	0
Period 2									
Option A (Final Rule)									
0 to 0.3	0	60	140	0	273	441	0	6,309,989	18,500,500
0.3 to 0.6	0	7	0	0	46	0	0	365,713	0
0.6 to 0.9	0	0	0	0	1	0	0	443,000	0
0.9 to 1.2	0	0	0	0	0	0	0	0	0
>1.2	0	1	0	0	3	0	0	146,817	0
Option B									
0 to 0.3	0	67	133	0	292	422	0	11,365,670	13,444,819
0.3 to 0.6	0	7	0	0	46	0	0	365,713	0
0.6 to 0.9	0	0	0	0	1	0	0	443,000	0
0.9 to 1.2	0	0	0	0	0	0	0	0	0
>1.2	0	1	0	0	3	0	0	146,817	0

Table 4-3: Estimated Distribution of Changes in Source Water and PWS-Level Iodine Concentrations by Period and Regulatory Option, Compared to Baseline

ΔI Range (µg/L)	Number of Source Water Reaches			Number of PWS[a]			Population Served by PWS		
	Positive[b] ΔI	Negative[b] ΔI	No ΔI (ΔI = 0)	Positive[b] ΔI	Negative[b] ΔI	No ΔI (ΔI = 0)	Positive[b] ΔI	Negative[b] ΔI	No ΔI (ΔI = 0)
Option C									
0 to 0.3	0	110	4	0	402	16	0	14,086,251	453,441
0.3 to 0.6	0	33	0	0	139	0	0	5,025,163	0
0.6 to 0.9	0	23	0	0	75	0	0	2,262,198	0
0.9 to 1.2	0	17	0	0	54	0	0	601,109	0
>1.2	0	21	0	0	78	0	0	3,337,857	0

a. Includes systems potentially directly and/or indirectly affected by steam electric power plant discharges.

b. Positive values indicate higher estimated iodine concentrations under the regulatory option as compared to the baseline, whereas negatives values indicate lower iodine concentrations under the regulatory option.

Option D is omitted from this table because EPA did not conduct this analysis at proposal. See the 2019 *BCA* (U.S. EPA, 2019a).

Source: U.S. EPA Analysis, 2020.

4.2 Additional Measures of Human Health Effects from Exposure to Steam Electric Pollutants via Drinking Water Pathway

The regulatory options may result in small changes to source water quality for additional parameters that can adversely affect human health (see Section 2.1.1). Many pollutants in steam electric power plant discharges have MCLs that set allowable levels in treated water. For some pollutants that have an MCL above the MCLG, there may be incremental benefits from reducing concentrations below the MCL.

Estimated concentrations of arsenic and lead in drinking water source reaches downstream of steam electric facilities do not exceed typical detection limits for these contaminants. The results show thallium concentrations in source waters that exceed levels detectable by standard methods (0.005 µg/L) in one source water reach but are below 0.005 µg/L in all other modeled source waters. Relative to baseline concentrations, the changes in arsenic, lead, and thallium concentrations are very small.

Table 4-4 summarizes the direction of changes in arsenic, lead, and thallium concentrations under the regulatory options[43] for the two analysis periods. The direction of the changes depends on the Period, regulatory option, source water reach, and PWS but is generally consistent with the changes in halogen loadings associated with FGD wastewater and bottom ash transport water under each analyzed regulatory option (see Table 3-3). During Period 1, Options A and B show either increases or no changes in arsenic, lead, and thallium concentrations for all source waters and PWS and Option C shows both increases and decreases in arsenic, lead, and thallium concentrations across locations. During Period 2, the three options show estimated increases and decreases in arsenic, lead, and thallium concentrations with both the magnitude and scope (the number of reaches, PWS, and population served) of the decreases larger than during Period 1.

To assess potential additional drinking water-related health benefits, EPA estimated the changes in the number of receiving reaches with drinking water intakes that have modeled pollutant concentrations in excess of MCLs or MCLGs. EPA did this analysis for all of the pollutants listed in Table 2-2, except bromate and TTHM. This analysis showed no changes in the number of MCL or MCLG exceedances under the regulatory options, when compared to the baseline. In addition, EPA found no reaches with drinking water intakes that had modeled lead, arsenic, or thallium concentrations in excess of MCLs or MCLGs under either the baseline or the regulatory options, even where concentrations increased as summarized in Table 4-4.[44] The Agency concluded, based on these screening analyses, that any additional benefits from changes in exposure to the pollutants examined in this analysis via the drinking water pathway would be very small.

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[43] Option D is omitted from this table because EPA did not conduct this analysis at proposal. See the 2019 *BCA* (U.S. EPA, 2019a).

[44] EPA also found that there are no reaches with drinking water intakes that have pollutant concentrations in excess of human health ambient water quality criteria for either the consumption of water and organism or the consumption of organism only.

Table 4-4: Estimated Distribution of Changes in Source Water and PWS-Level Arsenic, Lead, and Thallium Concentrations by Period and Regulatory Option, Compared to Baseline

Regulatory Option	Number of Source Water Reaches			Number of PWS[a]			Population Served by PWS		
	Positive[b] Change	Negative[b] Change	No Change	Positive[b] Change	Negative[b] Change	No Change	Positive[b] Change	Negative[b] Change	No Change
Period 1									
Arsenic									
Option A (Final Rule)	245	0	10	894	0	55	30,510,519	0	1,102,458
Option B	245	0	10	894	0	55	30,510,519	0	1,102,458
Option C	201	51	3	790	146	13	27,760,901	3,649,526	202,550
Lead									
Option A (Final Rule)	245	0	10	894	0	55	30,510,519	0	1,102,458
Option B	245	0	10	894	0	55	30,510,519	0	1,102,458
Option C	215	37	3	818	118	13	28,604,368	2,806,059	202,550
Thallium									
Option A (Final Rule)	245	0	10	894	0	55	30,510,519	0	1,102,458
Option B	245	0	10	894	0	55	30,510,519	0	1,102,458
Option C	113	139	3	495	441	13	8,936,558	22,473,869	202,550
Period 2									
Arsenic									
Option A (Final Rule)	215	27	13	690	201	58	28,650,054	1,874,283	1,088,640
Option B	215	27	13	690	201	58	28,650,054	1,874,283	1,088,640
Option C	76	174	5	270	666	13	12,591,406	18,826,772	194,799
Lead									
Option A (Final Rule)	219	23	13	735	156	58	29,514,216	1,010,121	1,088,640
Option B	219	23	13	735	156	58	29,514,216	1,010,121	1,088,640
Option C	130	120	5	489	447	13	22,539,805	8,878,373	194,799
Thallium									
Option A (Final Rule)	200	42	13	640	251	58	25,892,193	4,632,144	1,088,640
Option B	193	49	13	621	270	58	20,836,512	9,687,825	1,088,640
Option C	53	197	5	204	732	13	6,248,250	25,169,928	194,799

a. Includes systems potentially directly and/or indirectly affected by steam electric power plant discharges.

b. Positive values indicate higher estimated concentrations under the regulatory option as compared to the baseline, whereas negatives values indicate lower concentrations under the regulatory option.

Source: U.S. EPA Analysis, 2020.

4.3 Limitations and Uncertainties

Table 4-5 summarizes principal limitations and sources of uncertainties associated with the estimated changes in pollutant levels in source waters downstream from steam electric power plant discharges. Additional limitations and uncertainties are associated with the estimation of pollutant loadings (see U.S. EPA, 2020f). Note that the effect on benefits estimates indicated in the second column of the table refers to the magnitude of the benefits rather than the direction (*i.e.*, a source of uncertainty that tends to underestimate benefits indicates expectation for either larger forgone benefits or larger realized benefits).

Table 4-5: Limitations and Uncertainties in the Analysis of Human Health Benefits from Changes in Discharges of Halogens and Other Pollutants Via the Drinking Water Pathway

Uncertainty/Limitation	Effect on Benefits Estimate	Notes
For PWS with multiple sources of water, the analysis uses equal contributions from each source.	Uncertain	Data on the flow rates of individual source facilities are not available and EPA therefore estimated that all permanent active sources contribute equally to a PWS's total supply. Effects of the regulatory option may be greater or smaller than estimated, depending on actual supply shares.
Changes in bromide and iodine concentrations are analyzed for active permanent surface water intakes and reservoirs only.	Underestimate	The analysis includes only permanent active surface water facilities associated with non-transient PWS classified as "community water systems" that use surface water as primary source. To the extent that PWS using surface waters as secondary source or other non-permanent surface water facilities are affected, this approach understates the effects of the regulatory options.
Discharge monitoring data for bromide from steam electric power plants are limited and demonstrate significant variability based on site-specific factors.	Uncertain	Limited bromide monitoring data are available to assess bromide source water concentration estimates.
Discharge monitoring data for iodine from steam electric power plants are unavailable.	Uncertain	No iodine monitoring data are available to assess source water iodine concentration estimates.
Source water monitoring data are unavailable to confirm estimated iodine concentrations associated with steam electric power plant discharges in PWS source waters.	Uncertain	While some bromide monitoring data are available to assess source water bromide concentration estimates, no iodine monitoring data are available to assess iodine concentration estimates.
The analysis does not consider pollutant sources beyond those associated with steam electric power plants or TRI dischargers.	Underestimate	The analysis of other pollutants does not account for natural background and anthropogenic sources that do not report to TRI. This results in a potential underestimate of the number of waters exceeding the MCL or MCLG.

5 Human Health Effects from Changes in Pollutant Exposure via the Fish Ingestion Pathway

EPA expects the regulatory options to affect human health risk by changing effluent discharges to surface waters and, as a result, ambient pollutant concentrations in the receiving reaches. The *Supplemental EA* (U.S. EPA, 2020f) provides details on the health effects of steam electric pollutants. Recreational and subsistence fishers (and their household members) who consume fish caught in the reaches receiving steam electric power plant discharges could benefit from reduced pollutant concentrations in fish tissue. This chapter presents EPA's analysis of human health effects resulting from changes in exposure to pollutants in bottom ash transport water and FGD wastewater via the fish consumption pathway. The analyzed health effects include:

- Changes in exposure to lead: This includes changes in neurological and cognitive damages in children (ages 0-7) based on the impact of an additional IQ point on an individual's future earnings and the cost of compensatory education for children with learning delays.

- Changes in exposure to mercury: Changes in neurological and cognitive damages in infants from exposure to mercury *in-utero* based on the impact of an additional IQ point on an individual's future earnings.

- Changes in exposure to arsenic: Changes in incidence of cancer cases and the COI associated with treating skin cancer.

The total quantified human health effects included in this analysis represent only a subset of the potential health effects estimated to result from the regulatory options. While additional adverse health effects are associated with pollutants in bottom ash transport water and FGD wastewater (such as kidney damage from cadmium or selenium exposure, gastrointestinal problems from zinc, thallium, or boron exposure, and others), the lack of data on dose-response relationships[45] between ingestion rates and these effects precluded EPA from quantifying the associated health effects.

EPA's analysis of the monetary value of human health effects utilizes data and methodologies described in Chapter 3 and in the *Supplemental EA* (U.S. EPA, 2020f). The relevant data include the set of immediate and downstream reaches that receive steam electric power plant discharges (*i.e.*, affected reaches), as defined by the NHD COMID[46], the estimated ambient pollutant concentrations in receiving reaches, and estimated fish consumption rates among different age and ethnic cohorts for affected recreational and subsistence fishers.

Section 5.1 describes how EPA identified the population potentially exposed to pollutants from steam electric power plant discharges via fish consumption. Section 5.2 describes the methods for estimating fish tissue pollutant concentrations and potential exposure via fish consumption in the affected population. Sections 5.3 to 5.5 describe EPA's analysis of various human health endpoints potentially affected by the regulatory options, which are then summarized in Section 5.6. Section 5.7 provides additional measures of human health benefits. Section 5.8 describes limitations and uncertainties.

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[45] A dose response relationship is an increase in incidences of an adverse health outcome per unit increase in exposure to a toxin.

[46] A COMID is a unique numeric identifier for a given waterbody (reach), assigned by a joint effort of the United States Geological Survey and EPA.

In general, the estimated human health effects of the final rule, Option A, are small compared to baseline (see U.S. EPA, 2015a).

5.1 Population in Scope of the Analysis

The population in scope of the analysis (*i.e.*, individuals potentially exposed to steam electric pollutants via consumption of contaminated fish tissue) includes recreational and subsistence fishers who fish reaches affected by steam electric power plant discharges (including receiving and downstream reaches), as well as their household members. EPA estimated the number of people who are likely to fish affected reaches based on typical travel distances to a fishing site and presence of substitute fishing locations. EPA notes that the universe of sites potentially visited by recreational and subsistence fishers includes reaches subject to fish consumption advisories (FCA).[47] EPA expects that recreational fishers responses to FCA presence are reflected in their catch and release practices, as discussed below.

Since fish consumption rates vary across different age, racial and ethnic groups, and fishing mode (recreational versus subsistence fishing), EPA estimated potential health effects separately for a number of age-, ethnicity-, and mode-specific cohorts. For each Census Block Group (CBG) within 50 miles of an affected reach, EPA assembled 2017 American Community Survey data on the number of people in 7 age categories (0 to 1, 2, 3 to 5, 6 to 10, 11 to 15, 16 to 21, and 21 years or higher), and then subdivided each group according to 7 racial/ethnic categories:[48] 1) White non-Hispanic; 2) African-American non-Hispanic; 3) Tribal/Native Alaskan non-Hispanic; 4) Asian/Pacific Islander non-Hispanic; 5) Other non-Hispanic (including multiple races); 6) Mexican Hispanic; and 7) Other Hispanic[49]. Within each racial/ethnic group, EPA further subdivided the population according to recreational and subsistence fisher groups. The Agency assumed that the 95th percentile of the general population fish consumption rate is representative of the subsistence fisher consumption rate. Accordingly, the Agency assumed that 5 percent of the total fishers population practices subsistence fishing.[50] EPA also subdivided the affected population by income into poverty and non-poverty groups, based on the share of people below the federal poverty line.[51] After subdividing population groups by age, race, fishing mode, and the poverty indicator, each CBG has 196 unique population cohorts (7 age groups × 7 ethnic/racial groups × 2 fishing modes [recreational versus subsistence fishing] × 2 poverty status designations).

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[47] Based on EPA's review of studies documenting fishers' awareness of FCA and their behavioral responses to FCA, 57.0 percent to 61.2 percent of fishers are aware of FCA, and 71.6 percent to 76.1 percent of those who are aware ignore FCA (Burger, 2004, Jakus *et al.*, 1997; Jakus *et al.*, 2002; R. L. Williams *et al.*, 2000). Therefore, only 17.4 percent of fishers may adjust their behavior in response to FCA (U.S. EPA, 2015a). The analysis reflects EPA's expectations that fishers responses to FCA are reflected in their catch and release practices.

[48] The racial/ethnic categories are based on available fish consumption data as well as the breakout of ethnic/racial populations in Census data, which distinguishes racial groups within Hispanic and non-Hispanic categories.

[49] The Mexican Hispanic and Hispanic block group populations were calculated by applying the Census tract percent Mexican Hispanic and Hispanic to the underlying block-group populations, since these data were not available at the block-group level.

[50] Data are not available on the share of the fishing population that practices subsistence fishing. EPA assumed that 5 percent of people who fish practice subsistence fishing, based on the assumed 95th percentile fish consumption rate for this population in EPA's Exposure Factors Handbook (see U.S. Environmental Protection Agency, 2011).

[51] Poverty status is based on data from the Census Bureau's American Community Survey which determines poverty status by comparing annual income to a set of dollar values called poverty thresholds that vary by family size, number of children, and the age of the householder.

EPA distinguished the exposed population by racial/ethnic group and poverty status to support analysis of potential environmental justice (EJ) considerations from baseline exposure to pollutants in steam electric power plant discharges, and to allow evaluation of the effects of the regulatory options on mitigating any EJ concerns. See Chapter 14 for details of the EJ analysis. As noted below, distinguishing the exposed population in this manner also allows the Agency to account for differences in exposure among demographic groups, where supported by available data.

Equation 5-1 shows how EPA estimated the population potentially exposed to steam electric pollutants, *ExPop(i)(s)(c)*, for CBG *i* in state *s* for cohort *c*.

Equation 5-1.

$$\boldsymbol{ExPop(i)(s)(\mathrm{c})} = \boldsymbol{Pop(i)(\mathrm{c})} \times \%\boldsymbol{Fish(s)} \times \boldsymbol{CaR(c)}$$

Where:

Pop(i)(c) = Total CBG population in cohort c. Age and racial/ethnicity-specific populations in each CBG are based on data from the 2017 American Community Survey, which provides population numbers for each CBG broken out by age and racial/ethnic group. To estimate the population in each age- and ethnicity/race-specific group, EPA calculated the share of the population in each racial/ethnic group and applied those percentages to the population in each age group.

%Fish(s) = Fraction of people who live in households with fishers. To estimate what percentage of the total population participates in fishing, EPA used region-specific U.S. Fish and Wildlife Service (U.S. FWS, 2018) estimates of the population 16 and older who fish.[52] EPA assumed that the share of households that includes fishers is equal to the fraction of people over 16 who participate in recreational fishing.

CaR(c) = Adjustment for catch-and-release practices. According to U.S. FWS (U.S. FWS, 2006) data, approximately 23.3 percent of recreational fishers release all the fish they catch ("catch-and-release" fishers). Fishers practicing "catch-and-release" would not be exposed to steam electric pollutants via consumption of contaminated fish. For all recreational fishers, EPA reduced the affected population by 23.3 percent. EPA assumed that subsistence fishers do not practice "catch-and-release" fishing.

Table 5-1 summarizes the population living within 50 miles of reaches affected by steam electric power plant discharges (see Section 5.2.1 for a discussion of this distance buffer) and EPA's estimate of the population potentially exposed to the pollutants via consumption of subsistence- and recreationally-caught fish (based on 2017 population data and not adjusted for population growth during the analysis period). Of the total population, 16.0 percent live within 50 miles of an affected reach and participate in recreational and/or subsistence fishing, and 12.4 percent are potentially exposed to fish contaminated by steam electric pollutants in bottom ash transport water and/or FGD wastewater discharges.

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[52] The share of the population who fishes ranges from 8 percent in the Pacific region to 20 percent in the East South Central region. Other regions include the Middle Atlantic (10 percent), New England (11 percent), South Atlantic (15 percent), Mountain (15 percent), West South Central (17 percent), East North Central (17 percent), and West North Central (18 percent).

Table 5-1: Summary of Population Potentially Exposed to Contaminated Fish Living within 50 Miles of Affected Reaches (as of 2017)

Total population	133,802,146
Total fishers population[a]	21,338,805
Population potentially exposed to contaminated fish[b, c]	16,615,461

a. Total population living within 50 miles of an affected reach multiplied by the state-specific share of the population who fishes based on U.S. FWS (2018; between 8 percent and 20 percent, depending on the state).

b. Total fishers population adjusted to remove fishers practicing catch-and-release and who therefore do not consume self-caught fish.

c. Analysis accounts for projected population growth so that the average population in scope of the analysis over the period of 2021 through 2047 is 11.1 percent higher than the population in 2017 presented in the table, or 18.5 million people. The analysis estimates that the fraction of the U.S. population engaged in recreational and subsistence fishing remains constant from 2021 through 2047.

Source: U.S. EPA Analysis, 2020

5.2 Pollutant Exposure from Fish Consumption

EPA calculated an average fish tissue concentration for each pollutant for each CBG based on a length-weighted average concentration for all reaches within 50 miles. For each combination of pollutant, cohort and CBG, EPA calculated the average daily dose (ADD) and lifetime average daily dose (LADD) consumed via the fish consumption pathway.

5.2.1 Fish Tissue Pollutant Concentrations

The set of reaches that may represent a source of contaminated fish for recreational and subsistence fishers in each CBG depends on the typical distance fishers travel to fish. EPA assumed that fishers typically travel up to 50 miles to fish[53], and used this distance to estimate the relevant fishing sites for the population of fishers in each CBG.

Fishers may have several fishable sites to choose from within 50 miles of travel. To account for the effect of substitute sites, EPA assumed that fishing efforts are uniformly distributed among all the available fishing sites within 50 miles from the CBG (travel zone). For each CBG, EPA identified all fishable reaches within 50 miles (where distance was determined based on the Euclidean distance between the centroid of the CBG and the midpoint of the reach) and the reach length in miles.

EPA then calculated, for each CBG within the 50-mile buffer of a fishable reach, the fish tissue concentration of As, Hg, and lead (Pb). *Appendix D* describes the approach used to calculate fish tissue concentrations of steam electric pollutants in the baseline and under each of the regulatory options.

For each CBG, EPA then calculated the reach length ($Length_i$) weighted fish fillet concentration ($C_{Fish\_Fillet}(CBG)$) based on all fishable reaches within the 50 mile radius according to Equation 5-2:

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[53] Studies of fishers behavior and practices have made similar observations (*e.g.*, Sohngen *et al.*, 2015 and Sea Grant - Illinois-Indiana, 2018).

Equation 5-2.

$$C_{Fish_{Fillet_e}}(CBG) = \frac{\sum_{i=1}^{n} C_{Fish_{Fillet}}(i) * Length_i}{\sum_{i=1}^{n} Length_i}$$

5.2.2 Average Daily Dose

Exposure to steam electric pollutants via fish consumption depends on the cohort-specific fish consumption rates. Table 5-2 summarizes the average fish consumption rates, expressed in daily grams per kilogram of body weight (BW), according to the race/ethnicity and fishing mode. The rates reflect recommended values for consumer-only intake of finfish in the general population from all sources, based on EPA's Exposure Factors Handbook (U.S. EPA, 2011). For more details on these fish consumption rates, see the *Supplemental EA* (U.S. EPA, 2020f) and the uncertainty discussion in Section 5.8.

Table 5-2: Summary of Group-specific Consumption Rates for Fish Tissue Consumption Risk Analysis

Race/ Ethnicity[a]	EA Cohort Name[b]	Consumption Rate (g/kg BW/day)	
		Recreational	Subsistence
White (non-Hispanic)	Non-Hispanic White	0.67	1.9
African American (non-Hispanic)	Non-Hispanic Black	0.77	2.1
Asian/Pacific Islander (non-Hispanic)	Other, including Multiple Races	0.96	3.6
Tribal/Native Alaskan (non-Hispanic)	Other, including Multiple Races	0.96	3.6
Other non-Hispanic	Other, including Multiple Races	0.96	3.6
Mexican Hispanic	Mexican Hispanic	0.93	2.8
Other Hispanic	Other Hispanic	0.82	2.7

a. Each group is also subdivided into seven age groups (0-1, 2, 3-5, 6-10, 11-15, 16-20, Adult [21 or higher] and two income groups [above and below the poverty threshold]).

b. See *Supplemental EA* for details (U.S. EPA, 2020f).

Source: U.S. EPA Analysis, 2020

Equation 5-3 and Equation 5-4 show the cohort- and CBG-specific ADD and LADD calculations based on fish tissue concentrations, consumption rates, and exposure duration and averaging periods from U.S. EPA (2020f).

Equation 5-3.

$$\boldsymbol{ADD(c)(i) = \frac{C_{Fish_{Fillet}}(i) \times CR_{Fish}(c) \times F_{Fish}}{1000}}$$

Where:

$ADD(c)(i)$ = average daily dose of pollutant from fish consumption for cohort c in CBG i (milligrams[mg] per kilogram [kg] body weight [BW] per day)

$C_{fish\_fillet}(i)$ = average fish fillet pollutant concentration consumed by humans for CBG i (mg per kg)

$CR_{fish}(c)$ = consumption rate of fish for cohort c (grams per kg BW per day); see Table 5-2.

F_{fish} = fraction of fish from reaches within the analyzed distance from the CBG (percent; estimated value of 100%)[54]

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[54] Given the uncertainty inherent in this estimate, EPA conducted a sensitivity analysis using an alternative estimate. These results are summarized in DCN SE09336: *Alternative Value for Fraction of Fish Consumed from a Contaminated Source*.

Equation 5-4. $$LADD(c)(i) = \frac{ADD(c)(i) \times ED(c) \times EF}{AT \times 365}$$

Where:

$LADD\ (c)(i)$ = lifetime average daily dose (mg per kg BW per day) for cohort c in CBG i

$ADD\ (c)(i)$ = average daily dose (mg per kg BW per day) for cohort c in CBG i

$ED(c)$ = exposure duration (years) for cohort c

EF = exposure frequency (days; set to 350)

AT = averaging time (years; set to 70)

EPA used the doses of steam electric pollutants as calculated above from fish caught through recreational and subsistence fishing in its analysis of benefits associated with the various human health endpoints described below.

5.3 Health Effects in Children from Changes in Lead Exposure

EPA's estimated changes in lead exposure relative to the baseline as a result of the regulatory options are small compared to those estimated in the 2015 analysis (see U.S. EPA, 2015a).

Lead is a highly toxic pollutant that can cause a variety of adverse health effects in children of all ages. In particular, elevated lead exposure may induce a number of adverse neurological effects in children, including decline in cognitive function, conduct disorders, attentional difficulties, internalizing behavior[55], and motor skill deficits (see National Toxicology Program [NTP], 2012; U.S. EPA, 2013c, 2019c, and 2020f). Elevated blood lead (PbB) concentrations in children may also slow postnatal growth in children ages one to 16, delay puberty in 8- to 17-year-olds, and decrease hearing and motor function (NTP, 2012; U.S. EPA, 2019c). Lead exposure is also associated with adverse health outcomes related to the immune system, including atopic and inflammatory responses (*e.g.*, allergy and asthma) and reduced resistance to bacterial infections. Studies have also found a relationship between lead exposure in expectant mothers and lower birth weight in newborns (NTP, 2012; U.S. EPA, 2019c; Zhu *et al.*, 2010). Because of data limitations, EPA estimated only the effects of changes in neurological and cognitive damages to pre-school (ages 0 to 7) children using the dose-response relationship for IQ decrements (Crump *et al.*, 2013).

EPA estimated health effects from changes in exposure to lead to preschool children using PbB as a biomarker of lead exposure. EPA modeled PbB under the baseline and regulatory option scenarios, and then used a concentration-response relationship between PbB and IQ loss to estimate changes in IQ losses in the affected population of children and changes in incidences of extremely low IQ scores (less than 70, or two standard deviations below the mean). EPA calculated the monetary value of changes in children's health effects based on the impact of an additional IQ point on an individual's future earnings and the cost of compensatory education for children with learning disabilities (including children with IQ less than 70 and PbB levels above 20 μg/dL).

EPA used the methodology described in Section 5.1 to estimate the population of children from birth to age seven who live in recreational fisher and subsistence fisher households and are potentially exposed to lead via consumption of contaminated fish tissue. EPA notes that fish tissue is not the only route of exposure to lead

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[55] Behavioral difficulties in children may include both externalizing behavior (*e.g.*, inattention, impulsivity, conduct disorders), and internalizing behaviors (*e.g.*, withdrawn behaviors, symptoms of depression, fearfulness, and anxiety).

among children. Other routes of exposure may include drinking water, dust, and other food. EPA used reference exposure values for these other routes of lead exposures and held these values constant for the baseline and regulatory options scenarios. Since this health effect applies to children up to the seventh birthday only, EPA restricted the analysis to the relevant age cohorts of fisher household members.

5.3.1 Methods

This analysis considers children who are born after implementation of the regulatory options and live in recreational fisher and subsistence fisher households. It relies on EPA's Integrated Exposure, Uptake, and Biokinetics (IEUBK) Model for Lead in Children (U.S. EPA, 2009b), which uses lead concentrations in a variety of media – including soil, dust, air, water, and diet – to estimate total exposure to lead for children in seven one-year age cohorts from birth through the seventh birthday. Based on this total exposure, the model generates a predicted geometric mean PbB for a population of children exposed to similar lead levels. See the 2013 BCA report (U.S. EPA, 2013a) for details.

For each CBG, EPA used the cohort-specific ADD based on Equation 5-3. EPA then multiplied the cohort-specific ADD by the average body weight for each age group[56] to calculate the "alternative source" input for the IEUBK model. Lead bioavailability and uptake after consumption vary for different chemical forms. Many factors complicate the estimation of bioavailability, including nutritional status and timing of meals relative to lead intake. For this analysis, EPA used the default media-specific bioavailability factor for the "alternative source" provided in the IEUBK model, which is 50 percent for oral ingestion.

EPA used the IEUBK model to generate the geometric mean PbB for each cohort in each CBG under the baseline and post-technology implementation scenarios. The IEUBK model processes daily intake to two decimal places (µg/day). For this analysis, this means that some of the change between the baseline and regulatory options is not accounted for by using the model (*i.e.*, IEUBK does not capture very small changes), since the estimated changes in health effects are driven by very small changes across large populations. This aspect of the model contributes to potential underestimation of the lead-related health effects in children arising from the regulatory options.

5.3.1.1 Estimating Changes in IQ Point Losses

EPA used the Crump *et al.* (2013) dose-response function to estimate changes in IQ losses between the baseline and regulatory options. Comparing the baseline and regulatory option results provides the changes in IQ loss per child. Crump *et al.* (2013) concluded that there was statistical evidence that the exposure-response is non-linear over the full range of PbB. Equation 5-5 shows an exposure-response function that represents this non-linearity:

Equation 5-5. $$\Delta \boldsymbol{IQ} = \beta_1 \times \boldsymbol{ln}(\boldsymbol{PbB} + \mathbf{1})$$

Where:

β_1 = -3.315 (log-linear regression coefficient on the lifetime blood lead level[57])

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[56] The average body weight values are 11.4 kg for ages 0 to 2, 13.8 kg for ages 2 to less than 3, 18.6 kg for ages 3 to less than 6, and 31.8 kg for ages 6 to 7.

[57] The lifetime blood lead level in children ages 0 to 7 is defined as a mean from six months of age to present (Crump *et al.*, 2013).

Multiplying the result by the number of affected pre-school children yields the total change in the number of IQ points for the affected population of children for the baseline and each regulatory option.

The IEUBK model estimates the mean of the PbB distribution in children, assuming a continuous exposure pattern for children from birth through the seventh birthday. The 2017 American Community Survey indicates that children ages 0 to 7 are approximately evenly distributed by age. To get an annual estimate of the number of children that would benefit from implementation of the regulatory options, EPA divided the estimated number of affected pre-school children by 7. This division adjusts the equation to apply only to children age 0 to 1. The estimated changes in IQ loss is thus an annual value (*i.e.*, it would apply to the cohort of children born each year after implementation).[58] Equation 5-6 shows this calculation for the annual increase in total IQ points.

Equation 5-6. $$\Delta \boldsymbol{IQ}(\boldsymbol{i})(\boldsymbol{c}) = \left(\mathbf{ln}\left(\Delta \boldsymbol{GM}(\boldsymbol{i})(\boldsymbol{c})\right) \times \mathbf{CRF} \times \left(\frac{\boldsymbol{ExCh}(\boldsymbol{i})(\boldsymbol{c})}{\mathbf{7}}\right)\right)$$

Where:

$\Delta IQ(i)(c)$ = the difference in total IQ points between the baseline and regulatory option scenarios for cohort *c* in CBG *i*

$Ln(\Delta GM(i)(c))$ = the log-linear change in the average PbB in affected population of children (µg/dL) for cohort *c* in CBG *i*

CRF = -3.315, the log-linear regression coefficient from Crump *et al.* (2013)

ExCh(i)(c) = the number of affected children aged 0 to 7 for cohort *c* in CBG *i*

The available economic literature provides little empirical data on society's overall WTP to avoid a decrease in children's IQ. To estimate the value of avoided IQ losses, EPA used estimates of the changes in a child's future expected lifetime earnings per one IQ point reduction and the cost of compensatory education for children with learning disabilities.

EPA estimated the value of an IQ point using the methodology presented in Salkever (1995) but with more recent data from the 1997 National Longitudinal Survey of Youth (U.S. EPA, 2019b). Updated results based on Salkever (1995) indicate that a one-point IQ reduction reduces expected lifetime earnings by 2.63 percent. Table 5-3 summarizes the estimated values of an IQ point based on the updated Salkever (1995) analysis using 3 percent and 7 percent discount rates. These values are discounted to the third year of life to represent the midpoint of the exposed children population. EPA also used an alternative value of an IQ point from Lin *et al.* (2018) in a sensitivity analysis (see *Appendix G*).

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[58] Dividing by seven undercounts overall benefits. Children from ages 1 to 7 (*i.e.*, born prior to the base year of the analysis) are not accounted for in the analysis, although they are also affected by changes in lead exposure.

Table 5-3: Value of an IQ Point (2018$) based on Expected Reductions in Lifetime Earnings

Discount Rate	Value of an IQ Point[a,b] (2018$)
3 percent	$20,832
7 percent	$4,358

a. Values are adjusted for the cost of education.

b. EPA adjusted the value of an IQ point to 2018 dollars using the GDP deflator.

Source: U.S. EPA, 2019b re-analysis of data from Salkever (1995)

5.3.1.2 Reduced Expenditures on Compensatory Education

Children whose PbB exceeds 20 μg/dL are more likely to have IQs less than 70, which means that they would require compensatory education tailored to their specific needs. Costs of compensatory education and special education are not reflected in the IQ point dollar value. Reducing exposure to lead at an early age is expected to reduce the incidence of children requiring compensatory and/or special education, which would in turn lower associated costs. Though these costs are not a substantial component of the overall benefits, they do represent a potential benefit of changes in lead exposure. EPA quantitatively assessed this benefit category using the methodology from the 2015 *BCA* (U.S. EPA, 2015a). The estimated cost savings from the estimated changes in the need of compensatory education are negligible and are not included in the total monetized benefits.

5.3.2 Results

Table 5-4 shows the monetary values associated with changes in IQ losses from lead exposure via fish consumption. EPA estimated that regulatory options A and B lead to slight increases in lead exposure and, as a result, forgone benefits, whereas Option C results in slight decreases in exposure to lead. The total net change in IQ point losses over the entire population of children with changes in lead exposure ranges from -19 (Option A) points to 12 points (Options C). Annualized monetary values of changes in IQ losses range from approximately -$16,000 (Option A) to $7,000 (Option C) using a 3 percent discount, and approximately -$4,000 (Option A) to $1,000 (Option C) using a 7 percent discount.

Table 5-4: Estimated Monetary Value of Changes in IQ Points for Children Exposed to Lead under the Regulatory Options, Compared to Baseline

Regulatory Option	Average Annual Number of Children 0 to 7 in Scope of the Analysis[c]	Total Change in IQ Point Losses, 2021 to 2047 in All Children 0 to 7 in Scope of the Analysis[d]	Annualized Value of Changes in IQ Points[a,b] (Thousands 2018$)	
			3% Discount Rate	7% Discount Rate
Option D[e]	*1,521,036*	*-4*	*-$3.0*	*-$0.7*
Option A (Final Rule)	1,615,629	-19	-$15.8	-$3.9
Option B	1,615,629	-11	-$10.5	-$2.9
Option C	1,615,629	12	$6.5	$0.7

a. Based on estimate that the loss of one IQ point results in the loss of 2.63 percent of lifetime earnings, following updated Salkever (1995) values from U.S. EPA (2019b).

b. Negative values represent forgone benefits.

c. The number of children in scope of the analysis is based on reaches analyzed across the regulatory options. Some of the children included in this count see no changes in exposure under some options.

Table 5-4: Estimated Monetary Value of Changes in IQ Points for Children Exposed to Lead under the Regulatory Options, Compared to Baseline

Regulatory Option	Average Annual Number of Children 0 to 7 in Scope of the Analysis[c]	Total Change in IQ Point Losses, 2021 to 2047 in All Children 0 to 7 in Scope of the Analysis[d]	Annualized Value of Changes in IQ Points[a,b] (Thousands 2018$)	
			3% Discount Rate	7% Discount Rate

d. EPA notes that the IQ point losses are very small. EPA further notes that the IEUBK model does not analyze blood lead level changes beyond two decimal points. EPA presents these estimates primarily for comparison to the 2015 final rule estimates.

e. Option D corresponds to the proposed Option 1. EPA did not reanalyze this option for the final rule. All results shown for Option D are based on the 2019 analysis, as detailed in the 2019 BCA (U.S. EPA, 2019a). As such, the values do not reflect changes in the baseline, plant universe, and other analytical inputs for the analysis of Options A, B, and C.

Source: U.S. EPA Analysis, 2020

5.4 Heath Effects in Children from Changes in Mercury Exposure

EPA estimated small changes in mercury exposure as a result of the regulatory options, compared to baseline (U.S. EPA, 2015a).

Mercury can have a variety of adverse health effects on adults and children (U.S. EPA, 2020f). The regulatory options may change the discharge of mercury to surface waters by steam electric power plants and therefore affect a range of human health effects. Due to data limitations, however, EPA estimated only the monetary value of the changes in IQ losses among children exposed to mercury *in-utero* as a result of maternal consumption of contaminated fish.

EPA identified the population of children exposed *in-utero* starting from the CBG-specific population in scope of the analysis described in *Section 5.1*. Because this analysis focuses only on infants born after implementation of the regulatory options, EPA further limited the analyzed population by estimating the number of women between the ages of 15 and 44 potentially exposed to contaminated fish caught in the affected waterbodies, and multiplying the result by ethnicity-specific average fertility rates.[59] This yields the cohort-specific annual number of births for each CBG.

The U.S. Department of Health and Human Services provides fertility rates by race for 2015 in the National Vital Statistics Report (Martin *et al.*, 2019). The fertility rate measures the number of births occurring per 1,000 women between the ages of 15 and 44 in a particular year. Fertility rates were highest for Hispanic women at 71.7, followed by African Americans at 64.1, Caucasians at 59.3, Asian or Pacific Islanders at 58.5, and Tribal/Other at 43.9.

5.4.1 Methods

EPA used the ethnicity- and mode-specific consumption rates shown in Table 5-2 and calculated the CBG- and cohort-specific mercury ADD based on Equation 5-3. In this analysis, EPA used a linear dose-response relationship between maternal mercury hair content and subsequent childhood IQ loss from Axelrad *et al.* (2007). Axelrad *et al.* (2007) developed a dose-response function based on data from three epidemiological studies in the Faroe Islands, New Zealand, and Seychelle Islands. According to their results, there is a 0.18-point IQ loss for each 1 part-per-million (ppm) increase in maternal hair mercury.

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[59] EPA acknowledges that fertility rates vary by age. However, the use of a single average fertility rate for all ages is not expected to bias results because the average fertility rate reflects the underlying distribution of fertility rates by age.

To estimate maternal hair mercury concentrations based on the daily intake (see Section 5.2.2), EPA used the median conversion factor derived by Swartout and Rice (2000), who estimated that a 0.08 µg/kg body weight increase in daily mercury dose is associated with a 1 ppm increase in hair concentration. Equation 5-7 shows EPA's calculation of the total annual IQ changes for a given receiving reach.

Equation 5-7. $$\boldsymbol{IQL(i)(c) = InExPop(i)(c) * MADD(i)(c) * \left(\frac{1}{Conv}\right) * DRF}$$

Where:

IQL(i) = IQ changes associated with *in-utero* exposure to mercury from maternal consumption of fish contaminated with mercury for cohort *c* in CBG *i*

InExPop(i)(c) = population of infants in scope of the analysis for cohort *c* in CBG *i* (the number of births)

MADD(i)(c) = maternal ADD for cohort *c* in CBG *i* (µg/kg BW/day)

Conv = conversion factor for hair mercury concentration based on maternal mercury exposure (0.08 µg/kg BW/day per 1 ppm increase in hair mercury)

DRF = dose response function for IQ decrement based on marginal increase in maternal hair mercury (0.18 point IQ decrement per 1 ppm increase in hair mercury)

Summing estimated IQ changes across all analyzed CBGs yields the total changes in the number of IQ points due to *in-utero* mercury exposure from maternal fish consumption under each analyzed regulatory option. The benefits of the regulatory options are calculated as the change in IQ points between the baseline and modeled post-technology implementation conditions under each of the regulatory options.

The available economic literature provides little empirical data on society's overall WTP to avoid a decrease in children's IQ. To estimate the value of avoided IQ losses, EPA used estimates of the changes in a child's future expected lifetime earnings per one IQ point reduction. The values of an IQ point presented in Section 5.3.1 are discounted to the third year of life to represent the midpoint of the exposed children population of interest for that analysis. EPA further discounted the present value of lifetime income differentials three additional years to reflect the value of an IQ point at birth and better align the benefits of reducing exposure to mercury with in-utero exposure (U.S. EPA, 2019d). The IQ values discounted to birth range from $3,704 to $19,064. EPA also used an alternative value of an IQ point from Lin *et al.* (2018) in a sensitivity analysis (see *Appendix G*).

5.4.2 Results

Table 5-5 shows the estimated changes in IQ point losses for infants exposed to mercury in-utero and the corresponding monetary values, using 3 percent and 7 percent discount rates. Regulatory options A and B result in a small net increase in IQ losses and, as a result, in forgone benefits to society. Option C results in a small net decrease in IQ point losses , with decreases in Period 2 larger than initial increases in Period 1. The annualized value of changes in IQ losses for Option C is negative despite the overall decrease in IQ point losses due to discounting. Using a 3 percent discount rate, the monetary values of increased IQ losses range from -$0.32 million (Option A) to -$0.11 million (Option C). Using a 7 percent discount rate, estimates range from -$0.11 million (Option A) to -$0.07 million (Option C).

Table 5-5: Estimated Monetary Values of Changes in IQ Points for Infants from Mercury Exposure under the Regulatory Options, Compared to Baseline

Regulatory Option	Number of Infants in Scope of the Analysis per Year[c]	Total Change in IQ Point Losses, 2021 to 2047 in All Infants in Scope of the Analysis	Annualized Value of Changes in IQ Points[a,b] (Millions 2018$)	
			3% Discount Rate	7% Discount Rate
Option D[d]	*225,272*	*-411*	*-$0.31*	*-$0.06*
Option A (Final Rule)	225,537	-201	-$0.32	-$0.11
Option B	225,537	-144	-$0.28	-$0.10
Option C	225,537	71[e]	-$0.11	-$0.07

a. Based on the estimate that the loss of one IQ point results in the loss of 2.63 percent of lifetime earnings discounted to birth, following updated Salkever (1995) values from U.S. EPA (2019d).

b. Negative values represent forgone benefits.

c. The number of infants in scope of the analysis is based on reaches analyzed across the regulatory options. Some of the children included in this count see no changes in exposure under some options.

d. Option D corresponds to the proposed Option 1. EPA did not reanalyze this option for the final rule. All results shown for Option D are based on the 2019 analysis, as detailed in the 2019 *BCA* (U.S. EPA, 2019a). As such, the values do not reflect changes in the baseline, plant universe, and other analytical inputs for the analysis of Options A, B, and C.

e. Although Option C results in a small net decrease in IQ point losses (or positive benefits) due to larger decreases in Period 2 than initial increases in Period 1, the annualized value for Option C is negative due to discounting.

Source: U.S. EPA Analysis, 2020

5.5 Estimated Changes in Cancer Cases from Arsenic Exposure

Among steam electric pollutants that can contaminate fish tissue and are analyzed in the *Supplemental EA*, arsenic is the only confirmed carcinogen with a published dose response function (see U.S. EPA, 2010b).[60] EPA used the methodology presented in Section 3.6 of the 2015 *BCA* (U.S. EPA, 2015a) to estimate the number of annual skin cancer cases associated with consumption of fish contaminated with arsenic from steam electric power plant discharges under the baseline and the change corresponding to each regulatory option and the associated monetary values. EPA's analysis shows no changes in skin cancer cases from exposure to arsenic via fish consumption are expected under the regulatory options. Accordingly, the estimated benefits are zero under all regulatory options.

5.6 Total Monetary Values of Estimated Changes in Human Health Effects

Table 5-6 presents the estimated monetary value of changes in adverse human health outcomes under the regulatory options. Using a 3 percent discount rate, the estimated monetary values range from -$0.34 million (Option A) to -$0.10 million (Option C). Using a 7 percent discount rate, the estimated monetary values range from -$0.11 million (Option A) to -$0.07 million (Option C). Negative values reflect forgone benefits. Changes in mercury exposure for children account for the majority of total monetary values from increases in adverse health outcomes.

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[60] Although other pollutants, such as cadmium, are also likely to be carcinogenic (see U.S. Department of Health and Human Services, 2012), EPA did not identify dose-response functions to quantify the effects of changes in these other pollutants.

Table 5-6: Total Monetary Values of Changes in Human Health Outcomes Associated with Fish Consumption under the Regulatory Options, Compared to Baseline (Millions of 2018$)

Discount Rate	Regulatory Option	Changes in Lead Exposure for Children[a,b,c]	Changes in Mercury Exposure for Children[a,b]	Changes in Cancer Cases from Arsenic	Total[a,b]
3%	*Option D[d]*	*<$0.00*	*-$0.31*	*$0.00*	*-$0.31*
	Option A (Final Rule)	-$0.02	-$0.32	$0.00	-$0.34
	Option B	-$0.01	-$0.28	$0.00	-$0.29
	Option C	$0.01	-$0.11	$0.00	-$0.10
7%	*Option D[d]*	*<$0.00*	*-$0.06*	*$0.00*	*-$0.06*
	Option A (Final Rule)	<$0.00	-$0.11	$0.00	-$0.11
	Option B	<$0.00	-$0.10	$0.00	-$0.10
	Option C	>$0.00	-$0.07	$0.00	-$0.07

a. Negative values represent forgone benefits and positive values represent realized benefits.

b. Based on the estimate that the loss of one IQ point results in the loss of 2.63 percent of lifetime earnings, following updated Salkever (1995) values from U.S. EPA (2019b).

c. "<$0.00" indicates monetary values greater than -$0.01 million but less than $0.00 million. ">$0.00" indicates monetary values greater than $0.00 million but less than $0.01 million.

d. Option D corresponds to the proposed Option 1. EPA did not reanalyze this option for the final rule. All results shown for Option D are based on the 2019 analysis, as detailed in the 2019 BCA (U.S. EPA, 2019a). As such, the values do not reflect changes in the baseline, plant universe, and other analytical inputs for the analysis of Options A, B, and C.

Source: U.S. EPA Analysis, 2020

5.7 Additional Measures of Potential Changes in Human Health Effects

As noted in the introduction to this chapter, untreated pollutants in steam electric power plant discharges have been linked to additional adverse human health effects. EPA compared immediate receiving water concentrations to human health-based NRWQC in U.S. EPA (2020f). To provide an additional measure of the potential health effects of the regulatory options, EPA also estimated the changes in the number of receiving and downstream reaches with pollutant concentrations in excess of human health-based NRWQC. This analysis compares pollutant concentrations estimated for the baseline and each analyzed regulatory option in receiving reaches and downstream reaches to criteria established by EPA for protection of human health. EPA compared estimated in-water concentrations of antimony, arsenic, barium, cadmium, chromium, cyanide, copper, lead, manganese, mercury, nitrate-nitrite as N, nickel, selenium, thallium, and zinc to EPA's NRWQC protective of human health used by states and tribes (U.S. EPA, 2018c) and to MCLs.[61] Estimated pollutant concentrations in excess of these values indicate potential risks to human health. This analysis and its findings are not additive to the preceding analyses in this chapter, but instead represent another way of characterizing potential health effects resulting from changes in exposure to steam electric pollutants.

Table 5-7 shows the results of this analysis.[62] During Period 1, EPA estimates that with baseline steam electric pollutant discharges, concentrations of steam electric pollutants exceed human health criteria for at least one pollutant in 161 reaches based on the "consumption of water and organism" criteria, and 38 reaches based on the "consumption of organism only" criteria nationwide. EPA estimates that the total number of

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[61] For pollutants that do not have NRWQC protective of human health, EPA used MCLs. These pollutants include cadmium, chromium, lead, and mercury.

[62] Only reaches designated as fishable (*i.e.*, Strahler Stream Order larger than 1) were included in the NRWQC exceedances analysis.

reaches with exceedances during Period 1 will increase under all regulatory options. Under Option C, some reaches are also estimated to experience a reduction in the number of exceedances relative to baseline. During Period 2, concentrations of steam electric pollutants exceed human health criteria for at least one pollutant in 68 reaches based on the "consumption of water and organism" criteria, and 23 reaches based on the "consumption of organism only" criteria nationwide under the baseline scenario. The estimated number of reaches with exceedances of "consumption water and organism" criteria during Period 2 increases under Options A and B and decreases under Option C. The total number of reaches with exceedances of "consumption of organism only" criteria decreases under the three options.[63]

Table 5-7: Estimated Number of Reaches Exceeding Human Health Criteria for Steam Electric Pollutants

Regulatory Option	Number of Reaches with Ambient Concentrations Exceeding Human Health Criteria for at Least One Pollutant[a]		Number of Reaches with Higher Number of Exceedances, Relative to Baseline[b]		Number of Reaches with Lower Number of Exceedances, Relative to Baseline[c]	
	Consumption of Water + Organism	Consumption of Organism Only	Consumption of Water + Organism	Consumption of Organism Only	Consumption of Water + Organism	Consumption of Organism Only
Period 1						
Baseline	161	38	Not applicable	Not applicable	Not applicable	Not applicable
Option A (Final Rule)	223	71	71	40	0	0
Option B	223	70	71	39	0	0
Option C	230	65	79	36	10	4
Period 2						
Baseline	68	23	Not applicable	Not applicable	Not applicable	Not applicable
Option A (Final Rule)	88	17	26	0	6	6
Option B	88	17	26	0	6	6
Option C	34	2	26	0	65	23

a. Pollutants for which there was at least one exceedance in the baseline or regulatory options include antimony, arsenic, cadmium, cyanide, lead, manganese, and thallium in Period 1 and arsenic, cyanide, manganese, and thallium in Period 2.

b. Pollutants for which there was at least one reach with higher number of exceedances relative to baseline include antimony, arsenic, cadmium, cyanide, manganese, and thallium in Period 1 and arsenic in Period 2.

c. Pollutants for which there was at least one reach with lower number of exceedances relative to baseline include arsenic, manganese, and thallium in Period 1 and arsenic, cyanide, manganese, and thallium in Period 2.

Source: U.S. EPA Analysis, 2020

5.8 Limitations and Uncertainties

The analysis presented in this chapter does not include all possible human health effects associated with post-technology implementation changes in pollutant discharges due to lack of data on a dose-response relationship between ingestion rates and potential adverse health effects. Therefore, the total quantified human

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[63] EPA's analysis does not take into account the fact that the NPDES permit for each steam electric power plant, like all NPDES permits, is required to have limits more stringent than the technology-based limits established by an ELG, wherever necessary to protect water quality standards. Because this analysis does not project where a permit will have more stringent limits than those required by the ELG, it may overestimate any negative impacts to aquatic ecosystems and T&E species, including impacts that will not be realized at all because the permits will be written to include limits as stringent as necessary to meet water quality standards as required by the CWA.

health effects included in this analysis represent only a subset of the potential health effects estimated to result from the regulatory options. Section 2.1 provides a qualitative discussion of health effects omitted from the quantitative analysis.

The methodologies and data used in the analysis of adverse health outcomes due to consumption of fish contaminated with steam electric pollutants involve limitations and uncertainties. Table 5-8 summarizes the limitations and uncertainties and indicates the direction of the potential bias. Note that the effect on benefits estimates indicated in the second column of the table refers to the magnitude of the benefits rather than the direction (*i.e.*, a source of uncertainty that tends to underestimate benefits indicates expectation for either larger forgone benefits or larger realized benefits). Additional limitations and uncertainties associated with the EA analyses and data are discussed in the *Supplemental EA* (see U.S. EPA, 2020f).

Table 5-8: Limitations and Uncertainties in the Analysis of Human Health Effects via the Fish Ingestion Pathway

Uncertainty/Limitation	Effect on Benefits Estimate	Notes
Fishers are estimated to evenly distribute their activity over all available fishing sites within the 50-mile travel distance.	Uncertain	EPA estimated that all fishers travel up to 50 miles and distribute their visits over all fishable sites within the area. In fact, recreational and subsistence fishers may have preferred sites (*e.g.*, a site located closer to their home) that they visit more frequently. The characteristics of these sites, notably ambient water concentrations and fishing advisories, affects exposure to pollutants, but EPA does not have data to support a more detailed analysis of fishing visits. The impact of this approach on monetary estimates is uncertain since fewer/more fishers may be exposed to higher/lower fish tissue concentrations than estimated by EPA.
The exposed population is estimated based on households in proximity to affected reaches and the fraction of the general population who fish.	Uncertain	EPA estimated the share of households that includes fishers to be equal to the fraction of people over 16 who are fishers. This may double-count households with more than one fisher over 16. However, the exposed population may also include non-household members who also consume the catch.
Fish intake rates used in estimating exposure are based on recommended values for the general consumer population.	Uncertain	The fish consumption rates used in the analysis are based on the general consumer population which may understate or overstate the amount of fish consumed by fishers who may consume fish at higher or lower rates than the general population (*e.g.*, Burger, 2013; U.S. EPA, 2011, 2013b)
100 percent of fish consumed by recreational fishers is self- caught.	Overestimate	The fish consumption rates used in the analysis account for all fish sources, *i.e.*, store-bought or self-caught fish. Assuming that recreational fishers consume only self-caught fish may overestimate exposure to steam electric pollutants from fish consumption. The degree of the overestimate is unknown as the fraction of fish consumed that is self-caught varies significantly across different locations and population subgroups (*e.g.*, U.S. EPA, 2013b).

Table 5-8: Limitations and Uncertainties in the Analysis of Human Health Effects via the Fish Ingestion Pathway

Uncertainty/Limitation	Effect on Benefits Estimate	Notes
The number of subsistence fishers was set to equal 5 percent of the total number of fishers fishing the affected reaches.	Uncertain	The magnitude of subsistence fishing in the United States or individual states is not known. Using 5 percent may understate or overstate the number of potentially affected subsistence fishers (and their households) overall, and ignores potential variability in subsistence fishing rates across racial/ethnic groups and different geographic locations.
There is a 0.18 point IQ loss for each 1 ppm increase in maternal hair mercury (*i.e.*, the relationship is assumed to be linear).	Uncertain	The exact form of the relationship between maternal body mercury burden and IQ losses is uncertain. Using a linear relationship may understate or overstate the IQ losses resulting from a given change in mercury exposure.
For the mercury- and lead-related health impact analyses, EPA assessed IQ losses to be an appropriate endpoint for quantifying adverse cognitive and neurological effects resulting from childhood or in-utero exposures to lead and mercury (respectively).	Underestimate	IQ may not be the most sensitive endpoint. Additionally, there are deficits in cognitive abilities that are not reflected in IQ scores, including increased incidence of attention-related and problem behaviors (NTP, 2012 and U.S. EPA, 2005b). To the extent that these impacts create disadvantages for children exposed to mercury and lead in the absence of (or independent from) measurable IQ losses, this analysis may underestimate the social welfare effects of the regulatory options of changes in lead and mercury exposure.
The IEUBK model processes daily intake from "alternative sources" to 2 decimal places (µg/day).	Underestimate	Since the fish-associated pollutant intakes are small, some variation is missed by using this model (*i.e.*, it does not capture very small changes).
EPA did not monetize the health effects associated with changes in adult exposure to lead or mercury.	Underestimate	The scientific literature suggests that exposure to lead and mercury may have significant adverse health effects for adults (*e.g.*, Aoki *et al.*, 2016; Chowdhury *et al.*, 2018; Lanphear *et al.*, 2018). If measurable effects are occurring at current exposure levels, excluding the effects of increased adult exposure results in an underestimate of benefits.
EPA did not quantify other health effects in children from exposure to lead or mercury.	Underestimate	As discussed in Section 2.1, exposure to lead could result in additional adverse health effects in children (*e.g.*, low birth weight and neonatal mortality from in-utero exposure to lead, or neurological effects in children exposed to lead after age seven) (NTP, 2012; U.S. EPA, 2013c; U.S. EPA, 2019c). Additional neurological effects could also occur in children from exposure to mercury after birth (Mergler *et al.*, 2007; CDC, 2009). If measurable effects are occurring at current exposure levels, excluding additional health effects of increased children exposure results in an underestimate of benefits.

Table 5-8: Limitations and Uncertainties in the Analysis of Human Health Effects via the Fish Ingestion Pathway

Uncertainty/Limitation	Effect on Benefits Estimate	Notes
EPA did not assess combined health risk of multiple pollutants.	Uncertain	The combined health risk of multiple pollutants could be greater than from a single pollutant (Evans *et al.*, 2020). However, quantifying cumulative risk is challenging because a mixture of pollutants could affect a wide range of target organs and endpoints (ATSDR, 2004, 2009). For example, different carcinogens found in steam electric power plant discharges may affect different organs (*e.g.*, arsenic is linked to skin cancer while cadmium is linked to kidney cancer). Other synergistic effects may increase or lessen the risk.

6 Nonmarket Benefits from Water Quality Changes

As discussed in the *Supplemental EA* (U.S. EPA, 2020f), heavy metals, nutrients, and other pollutants discharged by steam electric power plants can have a wide range of effects on water resources downstream from the plants. These environmental changes affect environmental goods and services valued by humans, including recreation; commercial fishing; public and private property ownership; navigation; water supply and use; and existence services such as aquatic life, wildlife, and habitat designated uses. Some environmental goods and services (*e.g.*, commercially caught fish) are traded in markets, and thus their value can be directly observed. Other environmental goods and services (*e.g.*, recreation and support of aquatic life) cannot be bought or sold directly and thus do not have observable market values. This second type of environmental goods and services are classified as "nonmarket." The estimated changes in the nonmarket values of the water resources affected by the regulatory options (hereafter nonmarket benefits or disbenefits) are additive to market values (*e.g.*, avoided costs of producing various market goods and services).

The analysis of the nonmarket value of water quality changes resulting from the regulatory options follows the same approach EPA used in the analysis of the 2015 rule and 2019 proposal (U.S. EPA, 2015a, 2019a). This approach, which is briefly summarized below, involves:

- characterizing the change in water quality under the regulatory options relative to the baseline using a WQI and linking these changes to ecosystem services or potential uses that are valued by society (see Section 3.4.2),
- monetizing changes in the nonmarket value of affected water resources under the regulatory options using a meta-analysis of surface water valuation studies that provide data on the public's WTP for water quality changes (see Section 6.1).

The analysis accounts for changes in water quality resulting from changes in nutrient, sediment, and toxics concentrations in reaches potentially affected by bottom ash transport water and FGD wastewater discharges. The assessment uses the CBG as the geographic unit of analysis, assigning a radial distance of 100 miles from the CBG centroid. EPA estimates that households residing in a given CBG value water quality changes in all modeled reaches within this range, with all unaffected reaches being viable substitutes for affected reaches within the area around the CBG. *Appendix E* describes EPA's approach.

In general, the analysis shows that the estimated effects of the final rule on the nonmarket value of water quality result in small forgone benefits when compared to those estimated under baseline (see U.S. EPA, 2015a).

6.1 Estimated Total WTP for Water Quality Changes

EPA estimated economic values of water quality changes at the CBG level using results of a meta-analysis of 168 estimates of total WTP (including both use and nonuse values) for water quality improvements, provided by 65 original studies conducted between 1981 and 2017.[64] The estimated econometric model allows calculation of total WTP for changes in a variety of environmental services affected by water quality and valued by humans, including changes in recreational fishing opportunities, other water-based recreation, and

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[64] Although the potential limitations and challenges of benefit transfer are well established (Desvousges *et al.*, 1987), benefit transfers are a nearly universal component of benefit cost analyses conducted by and for government agencies. As noted by V. K. Smith *et al.* (2002, p. 134) , "nearly all benefit cost analyses rely on benefit transfers, whether they acknowledge it or not."

existence services such as aquatic life, wildlife, and habitat designated uses. The model also allows EPA to adjust WTP values based on the core geospatial factors predicted by theory to influence WTP, including: scale (the size of affected resources or areas), market extent (the size of the market area over which WTP is estimated), and the availability of substitutes. The meta-analysis regression is based on two models: Model 1 provides EPA's central estimate of non-market benefits and Model 2 develops a range of estimates that account for uncertainty in the WTP estimates. *Appendix G* provides details on how EPA used the meta-analysis to predict household WTP for each CBG and year as well as the estimated regression equation, intercept and variable coefficients for the two models used in this analysis. The appendix also provides the corresponding independent variable names and assigned values.

Based on the meta-analysis results, EPA multiplied the coefficient estimates for each variable (see Model 1 and Model 2 in Table G-1) by the variable levels calculated for each CBG or fixed at the levels indicated in the "Assigned Value" column in Table G-1. The sum of these products represents the predicted natural log of marginal household WTP (*ln_MWTP*) for a representative household in each CBG. Equation 6-1 provides the equation used to calculate household benefits for each CBG.

Equation 6-1.

$$HWTP_{Y,B} = MWTP_{Y,B} \times \Delta WQI_B$$

where:

$HWTP_{Y,B}$ = Annual household WTP in 2018$ in year *Y* for households located in the CBG (*B*),

$MWTP_{Y,B}$ = Marginal WTP for water quality for a given year (*Y*) and the CBG (*B*) estimated by the meta-analysis function and evaluated at the midpoint of the range over which water quality is changed,

ΔWQI_B = Estimated annual average water quality change for the CBG (*B*).

To estimate WTP for water quality changes under the regulatory options, EPA first estimated water quality changes for each year within Period 1 and Period 2 (see Section 3.2.1 for details) and then applied the meta-regression model (MRM) to estimate per household WTP for water quality improvements in a given year. Monetary values of water quality changes are estimated for all years from 2021 through 2047. As summarized in Table 6-1, average annual household WTP estimates for the regulatory options range from -$0.40 under Option A (low estimate) to -$0.14 under Option C (high estimate), for the regulatory options EPA analyzed.

Table 6-1: Estimated Household Willingness-to-Pay for Water Quality Changes under the Regulatory Options, Compared to Baseline

Regulatory Option	Number of Affected Households (Millions)[c]	Average Annual WTP Per Household (2018$)[a,b]		
		Low	Central	High
Option D[d]	*85.2*	*-$0.62*	*-$0.14*	*-$0.11*
Option A (Final Rule)	82.4	-$0.20	-$0.31	-$0.40
Option B	78.5	-$0.16	-$0.25	-$0.32
Option C	84.6	-$0.14	-$0.22	-$0.28

a. Negative values represent forgone benefits

b. Model 2 provides low and high estimates for each option, while Model 1 provides central estimates. EPA used ΔWQI equal to 5 units to develop low estimates and to 50 units to develop high estimates based on Model 2 (See *Appendix G* for details). The central estimate does not fall at the midpoint of the range, but instead represents the value from Model 1 which falls between the low and high bound estimates provided by Model 2.

c. The number of affected households varies across options because of differences in the number of reaches that have non-zero changes in water quality.

d. Option D corresponds to the proposed Option 1. EPA did not reanalyze this option for the final rule. All results shown for Option D are based on the 2019 analysis, as detailed in the 2019 BCA (U.S. EPA, 2019a). As such, the values do not reflect changes in the baseline, plant universe, and other analytical inputs for the analysis of Options A, B, and C.

Source: U.S. EPA Analysis, 2020

To estimate total WTP (TWTP) for water quality changes for each CBG, EPA multiplied the per-household WTP values for the estimated water quality change by the number of households within each block group in a given year and calculated the present value (PV) of the stream of WTP over the 27 years in EPA's period of analysis. EPA then calculated annualized total WTP values for each CBG using 3 percent and 7 percent discount rates as shown in Equation 6-2.

Equation 6-2.

$$TWTP_B = \left(\sum_{T=2021}^{2047} \frac{HWTP_{Y,B} \times HH_{Y,B}}{(1+i)^{Y-2020}} \right) \times \left(\frac{i \times (1+i)^n}{(1+i)^{n+1} - 1} \right)$$

where:

$TWTP_B$ = Annualized total household WTP in 2018$ for households located in the CBG (*B*),

$HWTP_{Y,B}$ = Annual household WTP in 2018$ for households located in the CBG (*B*) in year (*Y*),

$HH_{Y,B}$ = the number of households residing in the CBG (*B*) in year (*Y*),

T = Year when benefits are realized

i = Discount rate (3 or 7 percent)

n = Duration of the analysis (27 years)[65]

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[65] See Section 1.3.3 for details on the period of analysis.

EPA generated annual household counts for each CBG through the period of analysis based on projected population growth following the method described in Section 1.3.7. Table 6-2 presents the results for the 3 percent and 7 percent discount rates.

Table 6-2: Estimated Total Annualized Willingness-to-Pay for Water Quality Changes under the Regulatory Options, Compared to Baseline (Millions of 2018$)

Regulatory Option	Number of Affected Households (Millions)[c]	3% Discount Rate[a,b]			7% Discount Rate[a,b]		
		Low	Central	High	Low	Central	High
Option D[d]	*85.2*	*-$55.5*	*-$12.5*	*-$10.0*	*-$48.1*	*-$10.9*	*-$8.6*
Option A (Final Rule)	82.4	-$15.3	-$11.8	-$7.4	-$16.4	-$12.5	-$8.0
Option B	78.5	-$10.4	-$7.8	-$5.0	-$12.0	-$9.0	-$5.8
Option C	84.6	-$9.9	-$7.4	-$4.8	-$13.9	-$10.3	-$6.7

a. Negative values represent forgone benefits.

b. Model 2 provides low and high estimates for each option, while Model 1 provides central estimates. EPA used ΔWQI equal to 5 units to develop low estimates and to 50 units to develop high estimates based on Model 2 (see Appendix G for details). The central estimate does not fall at the midpoint of the range, but instead represents the value from Model 1 which falls between the low and high bound estimates provided by Model 2.

c. The number of affected households varies across options because of differences in the number of reaches that have non-zero changes in water quality.

d. Option D corresponds to the proposed Option 1. EPA did not reanalyze this option for the final rule. All results shown for Option D are based on the 2019 analysis, as detailed in the 2019 BCA (U.S. EPA, 2019a). As such, the values do not reflect changes in the baseline, plant universe, and other analytical inputs for the analysis of Options A, B, and C.

Source: U.S. EPA Analysis, 2020

The total annualized values of water quality changes resulting from changes in toxics, nutrient and sediment discharges in these reaches range from -$16.4 million under Option A (7 percent discount rate) to -$4.8 million under Option C (3 percent discount rate). The negative values indicate that all regulatory options result in net forgone benefits.

6.2 Limitations and Uncertainties

Table 6-3 summarizes the limitations and uncertainties in the analysis of benefits associated with changes in surface water quality and indicates the direction of any potential bias. Note that the effect on benefits estimates indicated in the second column of the table refers to the magnitude of the benefits rather than the direction (*i.e.*, a source of uncertainty that tends to underestimate benefits indicates expectation for larger forgone benefits or for larger realized benefits).

Table 6-3: Limitations and Uncertainties in the Analysis of Nonmarket Water Quality Benefits

Uncertainty/Limitation	Effect on Benefits Estimate	Notes
Use of 100-mile buffer for calculating water quality benefits for each CBG	Underestimate	The distance between the surveyed households and the affected waterbodies is not well measured by any of the explanatory variables in the meta-regression model. EPA would expect values for water quality changes to diminish with distance (all else equal) between the home and affected waterbody. The choice of 100 miles is based on typical driving distance to recreational sites (*i.e.*, 2 hours or 100 miles). Therefore, EPA used 100 miles to approximate the distance decay effect on WTP values. The analysis effectively assumes that people living farther than 100 miles place *no* value on water quality improvements for these waterbodies despite literature that shows that while WTP tends to decline with distance from the waterbody, people place value on the quality of waters outside their region.
Selection of the WQI parameter value for estimating low and high WTP values	Uncertain	EPA set ΔWQI to 5 and 50 units to estimate low and high benefit values using Model 2. These values were based on the lowest and highest water quality changes included in the meta-data. To the extent that ΔWQI = 50 is significantly larger than the change in water quality expected from the regulatory options, it is likely to significantly understate the estimated WTP value in absolute terms. ΔWQI = 5 is more consistent with the magnitude of water quality changes resulting from the regulatory options.
Potential hypothetical bias in underlying stated preference results	Uncertain	Following standard benefit transfer approaches, this analysis proceeds under the assumption that each source study provides a valid, unbiased estimate of the welfare measure under consideration (cf. Moeltner *et al.*, 2007; Rosenberger and Phipps, 2007). To minimize potential hypothetical bias underlying stated preference studies included in meta-data, EPA set independent variable values to reflect best benefit transfer practices.
Use of different water quality measures in the underlying meta-data	Uncertain	The estimation of WTP may be sensitive to differences in the environmental water quality measures across studies in the meta data. Studies that did not use the WQI were mapped to the WQI so a comparison could be made across studies. In developing the 2015 meta-regression models, EPA tested a binary variable (WQI) that captures the effect of a study using (WQI=1) or not using (WQI=0) the WQI. The variable coefficient was not statistically different from zero, indicating no evidence of systematic bias in the mapping of studies that did not use the WQI. However, the 2020 update of the meta-regression, which added 14 new studies to the 2015 meta-data, accounts for potential effects of the use of a different water quality metric (*i.e.*, index of biotic integrity (IBI)) on the interpretation of the baseline and water quality and improvements (see *Appendix G* for details).

Table 6-3: Limitations and Uncertainties in the Analysis of Nonmarket Water Quality Benefits

Uncertainty/Limitation	Effect on Benefits Estimate	Notes
Transfer error	Uncertain	Transfer error may occur when benefit estimates from a study site are adopted to forecast the benefits of a policy site. Rosenberger and Stanley (2006) define transfer error as the difference between the transferred and actual, generally unknown, value. While meta-analysis is fairly accurate when estimating benefit function, transfer error may be a problem in cases where the sample size is small. Meta-analyses have been shown to outperform other function-based transfer methods in many cases, but this result is not universal (Shrestha *et al.*, 2007). This notwithstanding, meta-analyses results are “very promising” for the performance of meta-analytic benefit transfers relative to alternative transfer methods (Rosenberger and Phipps, 2007).
Omission of Great Lakes and estuaries from analysis of benefits from water quality changes	Underestimate	Six out of 112 (5 percent) steam electric power plants discharge to the Great Lakes or estuaries. Due to limitations of the water quality models used in the analysis of the regulatory options, these waterbodies were excluded from the analysis. This omission likely underestimates benefits of water quality changes from the regulatory options.
The water quality model accounts for only a subset of sources of toxic pollutants contributing to baseline concentrations	Uncertain	The overall impact of this limitation on the estimated WTP for water quality changes is uncertain but is expected to be small since the estimated WTP is a function of a mid-point between the baseline and post-technology implementation water quality. Therefore, the difference in WTP between the baseline and post-technology implementation would be more sensitive to the estimated water quality changes.

7 Impacts and Benefits to Threatened and Endangered Species

7.1 Introduction

T&E species are species vulnerable to future extinction or at risk of extinction in the near future, respectively. These designations reflect low or rapidly declining population levels, loss of essential habitat, or life history stages that are particularly vulnerable to environmental alteration or other stressors. In many cases, T&E species are given special protection due to inherent vulnerabilities to habitat modification, disturbance, or other impacts of human activities. This chapter examines the projected change in environmental impacts of steam electric power plant discharges on T&E species and the estimated benefits associated with the projected changes resulting from the regulatory options.

As described in the 2015 *EA* and in the 2020 *Supplemental EA* (U.S. EPA, 2015b, 2020f), the untreated chemical constituents of steam electric power plant wastestreams can pose serious threats to ecological health due to the bioaccumulative nature of many pollutants, high concentrations, and high loadings. Pollutants such as selenium, arsenic and mercury have been associated with fish kills, disruption of growth and reproductive cycles and behavioral and physiological alterations in aquatic organisms. Additionally, high nutrient loads can lead to the eutrophication of waterbodies. Eutrophication can lead to increases in the occurrence and intensity of water column phytoplankton, including harmful algal blooms (*e.g.*, nuisance and/or toxic species), which have been found to cause fatal poisoning in other animals, fish, and birds. Eutrophication may also result in the loss of critical submerged rooted aquatic plants (or macrophytes), and reduced DO levels, leading to anoxic or hypoxic waters.

For species vulnerable to future extinction, even minor changes to growth and reproductive rates and small levels of mortality may represent a substantial portion of annual population growth. To quantify the estimated effects of the regulatory options compared to baseline, EPA conducted a screening analysis using changes in projected attainment of freshwater NRWQC as an indicator. Specifically, EPA identified the reaches that are projected to see changes in achievement of freshwater aquatic life NRWQC as a consequence of the regulatory options, assuming no more stringent controls are established to meet applicable water quality standards (*i.e.*, water-quality-based effluent limits issued under Section 301(b)(1)(C)) , relative to the baseline. Using these projections, EPA then estimated the number of T&E species whose recovery could be affected based on the species' habitat range. Because NRWQC are recommended at levels to protect aquatic organisms, reducing the frequency at which aquatic life-based NRWQC are exceeded could translate into reduced risk to T&E species and potential improvements in species populations.[66] Conversely, increasing the frequency of exceedances may increase risk to T&E species and decrease their survival or recovery.

In this chapter, EPA examines the current conservation status of species belonging to freshwater taxa and identifies the extent to which the regulatory options, independent of consideration of water quality-based controls, may benefit or adversely impact T&E species. Specifically, EPA estimated the changes in potential impacts of steam electric power plant discharges on surface waters intersecting habitat ranges of T&E species, to provide a quantitative, but unmonetized proxy for the benefits associated with the regulatory options.

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[66] Criteria are developed based on the 1985 Guidelines methods (U.S. EPA, 1985) and generally reflect high quality toxicity data from at least 8 different taxa groups that broadly represent aquatic organisms. To the extent that more stringent levels are required to protect organisms in a particular location, that is addressed during the water quality standard development process for that location.

The analysis generally follows the approach EPA used in 2015 and 2019 (U.S. EPA, 2015a, 2019a). However, in response to comments EPA received on the 2019 proposal, EPA updated inputs for the analysis from the critical habitat range data used in 2019 to the most current total habitat range data from the U.S. FWS in order to provide a more comprehensive assessment of the potential overlap between species ranges and affected reaches. EPA has also provided additional details on the identified overlaps (see *Appendix H*) and revised its description of the analysis below to clarify the methodology, assumptions, and inputs.

In general, the analysis shows the estimated effects of the final rule, Option A, on T&E species to be small compared to baseline (see U.S. EPA, 2015a).

7.2 Baseline Status of Freshwater Fish Species

Reviews of aquatic species' conservation status over the past three decades have documented the effect of cumulative stressors on freshwater aquatic ecosystems, resulting in a significant decline in the biodiversity and condition of indigenous communities (Deacon *et al.*, 1979; J. E. Williams *et al.*, 1989; J. D. Williams *et al.*, 1993; Taylor *et al.*, 1996; Taylor *et al.*, 2007; Jelks *et al.*, 2008). Overall, aquatic species are disproportionately imperiled relative to terrestrial species. For example, while 39 percent of freshwater and diadromous fish species are imperiled (Jelks *et al.*, 2008), a similar status review found that only 7 percent of North American bird and mammal species are imperiled (Wilcove & Master, 2005). Recent studies of threats and extinction trends in freshwater taxa also concluded that biodiversity is much more at risk in freshwater compared to marine ecosystems (Winemiller, 2018).

Approximately 39 percent of described fish species in North America are imperiled, with 700 fish taxa classified as vulnerable (230), threatened (190), or endangered (280) in addition to 61 taxa presumed extinct or functionally extirpated from nature (Jelks *et al.*, 2008). These data show that the number of T&E species have increased by 98 percent and 179 percent when compared to similar reviews conducted by the American Fisheries Society in 1989 (J. E. Williams *et al.*, 1989) and 1979 (Deacon *et al.*, 1979), respectively. Despite recent conservation efforts, including the listing of several species under the Endangered Species Act (ESA), only 6 percent of the fish taxa assessed in 2008 had improved in status since the 1989 inventory (Jelks *et al.*, 2008).

Several families of fish have high proportions of T&E species. Approximately 46 percent and 44 percent of species within families Cyprinidae (carps and true minnows) and Percidae (darters and perches) are imperiled, respectively. Some families with few, wide-ranging species have even higher rates of imperilment, including the Acipenseridae (sturgeons; 88 percent) and Polyodontidae (paddlefish; 100 percent). Families with species important to sport and commercial fisheries have imperilment levels ranging from a low of 22 percent for Centrarchidae (sunfishes) to a high of 61 percent for Salmonidae (salmon) (Jelks *et al.*, 2008).

7.3 T&E Species Potentially Affected by the Regulatory Options

To assess the potential effects of the regulatory options on T&E species, EPA used the U.S. FWS Environmental Conservation Online System (ECOS) to construct a database to analyze which species have habitats that overlap with waters projected to improve or degrade due to changes in pollutant discharge from steam electric power plants. The database includes all animal species currently listed or under consideration for listing under the ESA (U.S. FWS, 2020d).

7.3.1 Identifying T&E Species Potentially Affected by the Regulatory Options

To estimate the effects of the regulatory options on T&E species, EPA first compiled data on habitat ranges for all species currently listed or under consideration for listing under the ESA. EPA obtained the geographical distribution of T&E species in geographic information system (GIS) format from ECOS (U.S. FWS, 2020b).

EPA constructed a screening database using the spatial data on species habitat ranges and all NHD reaches downstream from steam electric power plants. This database included all T&E species whose habitat ranges intersect reaches immediately receiving or downstream of steam electric power plant discharges. EPA used a 200-meter buffer on either side of each reach when estimating the intersection to account for waterbody widths and any minor errors in habitat maps. This initial analysis identified a total of 197 T&E species.

EPA then classified these species on the basis of their vulnerability to changes in water quality for the purpose of assessing potential impacts of the regulatory options. EPA obtained species life history data from a wide variety of sources to assess T&E species' vulnerability to water pollution. For the purpose of this analysis, species were classified as follows:

- Higher vulnerability – species living in aquatic habitats for several life history stages and/or species that obtain a majority of their food from aquatic sources.
- Moderate vulnerability – species living in aquatic habitats for one life history stage and/or species that obtain some of their food from aquatic sources.
- Lower vulnerability – species whose habitats overlap bodies of water, but whose life history traits and food sources are terrestrial.

Table 7-1 summarize the results of this assessment. *Appendix H* lists all T&E species whose habitat ranges intersect reaches immediately receiving or downstream of steam electric power plant discharges.

Table 7-1: Number of T&E Species with Habitat Range Intersecting Reaches Immediately Receiving or Downstream of Steam Electric Power Plant Discharges, by Group

Species Group	Species Vulnerability			Species Count
	Lower	Moderate	Higher	
Amphibians	3	2	3	8
Arachnids	6	0	0	6
Birds	18	6	1	25
Clams	0	0	62	62
Crustaceans	0	2	3	5
Fishes	0	0	35	35
Insects	9	0	1	10
Mammals	14	1	1	16
Reptiles	15	1	3	19
Snails	2	0	9	11
Total	**67**	**12**	**116**	**197**

Source: U.S. EPA Analysis, 2020.

To estimate the potential impacts of the regulatory options, EPA focused the analysis on species with higher vulnerability potentials based upon life history traits. EPA's further review of this subset of species resulted in the removal from further analysis of those species endemic to isolated headwaters and natural springs, as these waters are unlikely to receive steam electric power plant discharges in the scope of the final rule (see *Appendix H* for details). Review of life history data for the remaining species shows pollution or water quality issues as one of the factors influencing species decline. This suggests that water quality issues may be important to species recovery even if not listed explicitly in species recovery plans.

7.3.2 Estimating Effects of the Rule on T&E Species

EPA used the results of the water quality model described in Chapter 3 to flag those reaches where estimated pollutant concentrations exceed the freshwater NRWQC under the baseline or the regulatory options (see Section 3.4.1.1). EPA estimated exceedances for two distinct periods (2021-2028 and 2029-2047) within the overall analysis period (2021-2047). As described in Section 3.2.1, Period 1 corresponds to the years when the steam electric power plants would be transitioning to treatment technologies to comply with the revised limits, whereas Period 2 reflects post-technology implementation conditions when all plants meet applicable revised limits.

EPA then linked the water quality model outputs with the species database described in the section above to identify potentially "affected T&E species habitats" where the water quality analysis shows changes under the regulatory options, meaning either: 1) the reaches intersecting the habitat range of a T&E species meet the NRWQC under baseline conditions but do not meet the NRWQC under one or more of the regulatory options (*i.e.*, potential forgone benefits); or 2) the reaches intersecting the habitat range of a T&E species do not meet the NRWQC under baseline conditions but do meet the NRWQC under one or more of the regulatory options (*i.e.*, potential positive benefits). EPA compared dissolved concentration estimates for eight pollutants to the freshwater acute and chronic NRWQC values[67] to assess the exceedance status of the reaches under the baseline and each regulatory option. The first condition occurs in a subset of reaches during Period 1, whereas the second condition is met for a subset of reaches during Period 2.

EPA identified a total of five species, listed in Table 7-2, whose habitat ranges intersect reaches that show changes in NRWQC exceedance status under the regulatory options during Period 1 and/or Period 2.

Table 7-2: Higher Vulnerability T&E Species with Habitat Intersecting Waters with Estimated Changes in NRWQC Exceedance Status under the Regulatory Options, Compared to Baseline

Species Group	Species Count	Species	Common Name
Clams	1	*Pleurobema clava*	Clubshell
Fishes	3	*Etheostoma trisella*	Trispot darter
		Gila cypha	Humpback chub
		Ptychocheilus lucius	Colorado pikeminnow (squawfish)
Mammals	1	*Trichechus manatus*	West Indian Manatee
Total	**5**		

Source: U.S. EPA Analysis, 2020.

Table 7-3 and Table 7-4 summarizes changes in exceedance status for Period 1 and Period 2, respectively. EPA's analysis shows that in Period 1 (2021-2028) a total of seven reaches within the habitat range of four T&E species have projected water quality degradation compared to baseline, as indicated by the NRWQC exceedance status. EPA estimated that no reaches would newly exceed the aquatic life NRWQC in Period 2 (2029-2047) under any of the regulatory options, when compared to the baseline. Further, the Period 1 exceedances in Table 7-3 are not present in Period 2.

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[67] The eight pollutants are arsenic, cadmium, copper, lead, mercury, nickel, selenium, and zinc. For more information about the aquatic life NRWQC, see Table C-7 in the *Supplemental EA* (U.S. EPA, 2020f).

EPA's analysis also indicates that three reaches that intersect habitat ranges of one T&E species (trispot darter) exceed NRWQC under the baseline conditions. The baseline exceedances are present in Period 1 (2021-2028) under all options, whereas water quality improvements in Period 2 (2029-2047) in three reaches under all regulatory options eliminate the estimated baseline exceedances and result in this species potentially benefiting from all three regulatory options (see Table 7-4).

Table 7-3: Higher Vulnerability T&E Species Whose Habitat May be Affected by the Regulatory Options Compared to Baseline in Period 1

Species Common Name	State	Number of Reaches with NRWQC Exceedances[a] for at Least One Pollutant in Period 1 (2021-2028)			
		Baseline	Option A (Final Rule)	Option B	Option C
Clubshell	KY	0	1	1	1
Colorado pikeminnow (=squawfish)	WY	0	5	5	5
Humpback chub	WY	0	5	5	5
West Indian Manatee	SC	0	0	0	1
Number of unique reaches with NRWQC exceedances		**0**	**6**	**6**	**7**

a. Exceedance counts are based on comparison of dissolved pollutant concentrations to NRWQC. Option D exceedances based on total pollutant concentrations are summarized in U.S. EPA (2019a).

Source: U.S. EPA Analysis, 2020.

Table 7-4: Higher Vulnerability T&E Species Whose Habitat May be Affected by the Regulatory Options Compared to Baseline in Period 2

Species Common Name	State	Number of Reaches with NRWQC Exceedances[a] for at Least One Pollutant in Period 2 (2029-2047)[a]			
		Baseline	Option A (Final Rule)	Option B	Option C
Trispot darter	GA	3	0	0	0
Number of unique reaches with NRWQC exceedances		**3**	**0**	**0**	**0**

a. Exceedance counts are based on comparison of dissolved pollutant concentrations to NRWQC. Option D exceedances based on total pollutant concentrations are summarized in U.S. EPA (2019a).

Source: U.S. EPA Analysis, 2020.

7.4 Limitations and Uncertainties

One limitation of EPA's analysis of the regulatory options' impacts on T&E species and their habitat is the lack of data necessary to quantitively estimate population changes of T&E species and to monetize these effects. The data required to estimate the response of T&E species populations to improved habitats are rarely available. In addition, understanding the contribution of T&E species to ecosystem functions can be challenging because: (1) it is often difficult to detect the location of T&E species, (2) experimental studies including rare or threatened species are limited; and (3) ecologists studying relationships between biodiversity and ecosystem functions typically focus on overall species diversity or estimate species contribution to ecosystem functions based on abundance (Dee *et al.*, 2019). Finally, much of the wildlife economic literature focuses on recreational benefits that are not relevant for many protected species (*i.e.*, use values) and the existing T&E valuation studies tend to focus on species that many people consider to be "charismatic" (*e.g.*, spotted owl, salmon) (Richardson & Loomis, 2009). Although a relatively large number of economic studies have estimated WTP for T&E protection, these studies focused on estimating WTP to avoid species loss/extinction, reintroduction, increase in the probability of survival, or a substantial increase in species population (Richardson and Loomis, 2006). In addition, Richardson and Loomis (2006) developed a meta-analysis of 31 stated preference studies valuing a variety of threatened, rare, or endangered species that allow estimation of WTP for avoiding species loss or changes in species population levels. However, use of this meta-regression model is not feasible for this analysis due to the challenges associated with estimating T&E population changes from the final rule. Table 7-5 summarizes limitations and uncertainties known to affect EPA's assessment of the impacts of the final rule on T&E species. Note that the effect on benefits estimates indicated in the second column of the table refers to the magnitude of the benefits rather than the direction (*i.e.*, a source of uncertainty that tends to underestimate benefits indicates expectation for larger forgone benefits or for larger realized benefits).

Table 7-5: Limitations and Uncertainties in the Analysis of T&E Species Impacts and Benefits

Uncertainty/Limitation	Effect on Benefits Estimate	Notes
The analysis does not account for water quality based effluent limits	Overestimate	This screening analysis is intended to isolate possible effects of the regulatory options on T&E species, however, it does not take into account the fact that the NPDES permits for each steam electric power plant, like all NPDES permits, are required to have limits more stringent than the technology-based limits established by an ELG wherever necessary to protect water quality standards. Because this analysis does not project where a permit will have more stringent limits than those required by the ELG, it may overestimate any negative impacts to T&E species, including impacts that will not be realized because the permits will be written to include limits as stringent as necessary to meet water quality standards as required by the CWA.
Intersection of T&E species habitat with reaches affected by steam electric plant discharges is used as proxy for exposure to steam electric pollutants	Overestimate	EPA used the habitat range as the basis for assessing the potential for impacts to the species from water quality changes. This approach is reasonable given the lack of reach-specific population data to support a national-level analysis, but the Agency acknowledges that the habitat range of a species does not necessarily indicate that the species is found in individual reaches within the habitat range.
The change in T&E species populations due to the effect of the regulatory options is uncertain	Uncertain	Data necessary to quantitatively estimate population changes are unavailable. Therefore, EPA used the methodology described in Section 7.3.1 as a screening-level analysis to estimate whether the regulatory options could contribute to a change in the recovery of T&E species populations.
Only those T&E species listed as threatened or endangered under the ESA are included in the analysis	Underestimate	The databases used to conduct this analysis include only species protected under the ESA. Additional species may be considered threatened or endangered by scientific organizations but are not protected by the ESA (*e.g.*, the American Fisheries Society [J. D. Williams *et al.*, 1993; Taylor *et al.*, 2007; Jelks *et al.*, 2008]). The magnitude of the underestimate is unknown. Although the proportion of imperiled freshwater fish and mussel species is high (*e.g.*, Jelks *et al.*, 2008; Taylor *et al.*, 2007) the geographic distribution of these species may or may not overlap with reaches affected by steam electric discharges.

Table 7-5: Limitations and Uncertainties in the Analysis of T&E Species Impacts and Benefits

Uncertainty/Limitation	Effect on Benefits Estimate	Notes
The potential for impact to T&E species is also present for changes in pollutant concentrations that don't result in changes in NRWQC exceedances	Underestimate	EPA's analysis quantifies changes in whether a NRWQC is exceeded in a given reach that intersects T&E species habitat ranges. However, changes in pollutant concentrations (either positive or negative) have the potential to result in impacts to T&E species even where they do not result in changes in NRWQC exceedance status. There are also potential impacts to T&E species from changes in pollutants for which freshwater NRWQC are not available (*e.g.*, salinity).
EPA's water quality model does not capture all sources of pollutants with a potential to impact aquatic T&E species	Uncertain	EPA's water quality model focuses on toxic pollutant discharges from steam electric power plants and certain other point sources, but does not account for other pollution sources (*e.g.*, historical contamination) or background levels. Adding these other sources or background levels could result in additional NRWQC exceedances under the baseline and/or regulatory options, but it is uncertain how the regulatory options would change the exceedance status of the intersected reaches.

8 Air Quality-Related Benefits

The regulatory options evaluated may affect air quality through three main mechanisms: 1) changes in energy used by steam electric power plants to operate wastewater treatment, ash handling, and other systems needed to meet the limitations and standards under the regulatory options; 2) transportation-related emissions due to the changes in trucking of CCR and other waste to on-site or off-site landfills; and 3) changes in the electricity generation profile from changes in wastewater treatment costs (and savings compared to the baseline) and the resulting changes in EGU relative operating costs. With respect to the third mechanism, the Integrated Planning Model (IPM) projects a 0.6 percent increase in electricity generation from coal in 2030 (+4,699 GWh) under the final rule compared to baseline. Because electricity demand is constant, this increase is offset by a 0.2 percent decline in generation from natural gas (-5,695 GWh) and renewable sources (-1,726 GWh), and a 0.4 percent increase in nuclear power generation (+2,292 GWh). See details in Chapter 5 of the *RIA* (U.S. EPA, 2020d). The changes in air emissions reflect the differences in EGU emissions factors for these other fuels or sources of energy, as compared to coal.

EPA estimated the climate-related benefits of changes in CO_2 emissions, as well as the human health benefits resulting from net changes in emissions of NO_X, SO_2, and directly emitted fine particulate matter ($PM_{2.5}$), also referred to as primary $PM_{2.5}$ emissions.

CO_2 is the most prevalent of the greenhouse gases, which are air pollutants that EPA has determined endanger public health and welfare through their contribution to climate change. EPA used estimates of the domestic social cost of carbon (SC-CO_2) to monetize the benefits of changes in CO_2 emissions as a result of the final rule. The SC-CO_2 is a metric that estimates the monetary value of projected impacts associated with marginal changes in CO_2 emissions in a given year. It includes a wide range of anticipated climate impacts, such as net changes in agricultural productivity and human health, property damage from increased flood risk, and changes in energy system costs, such as reduced costs for heating and increased costs for air conditioning.

$PM_{2.5}$ air pollution has been associated with a variety of adverse health effects detailed in the Integrated Science Assessments for Particulate Matter (PM ISA), including premature mortality and a variety of morbidity effects associated with acute and chronic exposures (U.S. EPA, 2009a, 2019e). In addition to primary $PM_{2.5}$ emitted directly by electricity generating units and other sources, NO_X and SO_X (which include SO_2 emissions quantified in this analysis) are known precursors to $PM_{2.5}$ air pollution. In addition, in the presence of sunlight, NO_X and volatile organic compounds (VOCs) can undergo a chemical reaction in the atmosphere to form ozone (O_3). Depending on localized concentrations of VOCs, changes in NO_X emissions also change human exposure to ozone. EPA's Integrated Science Assessments for *Ozone and Related Photochemical Oxidants* (Ozone ISA) identify a variety of potential health effects associated with acute and chronic ozone exposures, including premature mortality and a variety of morbidity effects (U.S. EPA, 2013d, 2020b). For the purpose of this analysis, EPA performed gridded photochemical air quality modeling and quantified the health benefits attributable to changes in $PM_{2.5}$ and ground-level ozone.[68] This BCA follows EPA's recent practice which has been to estimate the impact on total non-accidental premature mortality associated with the change in ozone exposure. However, the 2020 Ozone ISA concludes that the currently available evidence for cardiovascular effects and total mortality is suggestive of, but not sufficient to infer, a causal relationship with short-term (as well as long-term) ozone exposures (U.S. EPA, 2020b, sections

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[68] Changes in emissions of SO_2 and NO_X would also change ambient exposure to SO_2 and NO_2, respectively, but EPA did not quantify health effects from these exposures.

IS.4.3.4 and IS.4.3.5). As such, EPA is in the process of recalibrating its benefits estimates to model only premature mortality from respiratory causes (*i.e.*, non-respiratory causes of premature mortality associated with ozone exposure would no longer be estimated). Until a replacement method that only estimates the benefits associated with respiratory causes of premature mortality has been developed, EPA will be removing the estimate of the impact of reduced ozone exposure on premature mortality from its benefits estimates from subsequent rulemakings.

For the analysis of the 2015 rule, the EPA relied on estimates of national monetized benefits per ton of emissions avoided, which represented the total monetized human health benefits from changes in the adverse outcomes mentioned above (U.S. EPA, 2015a). For the proposed rule, the Agency quantified, but did not monetize, changes in emissions of $PM_{2.5}$ precursors NO_X and SO_2. For this final rule, EPA leveraged available photochemical modeling outputs that were created as part of the ACE rule RIA (U.S. EPA, 2019h). The full-scale modeling used in this analysis included annual model simulations for a 2011 base year and a 2023 future year to provide hourly concentrations of ozone and primary and secondarily formed $PM_{2.5}$ component species (*e.g.*, sulfate, nitrate, ammonium, elemental carbon (EC), organic aerosol (OA), and crustal material) for both years nationwide. EPA tracked the impact of specific emissions sources on ozone and $PM_{2.5}$ in the 2023 modeled case using a tool called "source apportionment." This air quality modeling approach provides spatially explicit estimates of concentration changes, which is required for characterizing uncertainty in mortality risk from changes in $PM_{2.5}$ concentrations at different levels of baseline $PM_{2.5}$ exposure. This is an important improvement in analytic method compared to the 2019 proposal and the 2015 rule because the air quality model is based on finer than national resolution of data where impacts are broken out based on state-level emission information and coal versus non-coal emissions for a subset of the fleet. This modeling also takes into account elemental carbon, organic carbon and crustal emissions, rather than elemental carbon and organic carbon used in the benefits per ton approach.

In addition, this air quality modeling also used a 2011 emission inventory projected to 2023 that reflects the current fleet of coal-fired power plants. The benefits-per-ton approach used a 2005 emission inventory projected to 2016. Changes in the location and emissions of facilities occurring between 2005 and 2011 would affect the size and distribution of PM changes, which will in turn affect the size of the estimated benefits. These differences in data and modeling can result in substantial differences in estimates of PM benefits or disbenefits.

As such, EPA will continue its current efforts to evaluate the usefulness of Reduced Form Tools (RFT), including a benefits per ton approach, in regulatory impact analysis and how they compare to Full Form Models (FFM). The areas of further evaluation between FFMs and RFTs would include for example, comparing the effect of differences in emissions including speciation of emissions (*e.g.*, crustal emissions versus elemental and organic carbon emissions), the impact of differences in model and data resolution, among other relevant areas, on the results from FFMs and RFTs.

The regulatory options evaluated may also affect air quality through changes in emissions of larger particulate matter (PM_{10}) and hazardous air pollutants (HAP) including Hg and HCl. The effects of mercury are detailed in the *Supplemental EA* (U.S. EPA, 2020f). HCl is a corrosive gas that can cause irritation of the mucous membranes of the nose, throat, and respiratory tract.

The following sections summarize the estimated changes in air emissions, describe the modeling and quantification methods, and present estimated benefits for two categories of benefits: climate change (Section 8.2) and human health (Section 8.3). More details about the methodology used to value benefits of

CO_2 changes and to model air quality changes can be found in *Appendix I* and *Appendix J*, respectively. Section 8.4 presents total annualized air benefits.

Section 8.5 summarizes major limitations and sources of uncertainty in the analysis of air quality-related benefits. Data, resource, and methodological limitations prevent EPA from estimating all domestic climate benefits and health and environmental benefits, including those from health effects from direct exposure to SO_2, NO_2, PM_{10}, and HAP, and ecosystem effects and visibility impairment. Chapter 2 discusses these unquantified effects.

In general, the analysis shows the estimated effects of the final rule on air quality to be smaller than those estimated for the baseline (see U.S. EPA, 2015a).

8.1 Changes in Air Emissions

As discussed in the *RIA*, EPA used IPM to estimate the electricity market-level effects of the final rule (Option A; see Chapter 5 in *RIA* [U.S. EPA, 2020d]). IPM outputs include estimated CO_2, NO_X, SO_2, Hg, and HCl emissions to air from EGUs. EPA also used IPM outputs to estimate EGU emissions of primary $PM_{2.5}$ and PM_{10} based on emission factors described in U.S. EPA (2020a). Specifically, EPA estimated primary $PM_{2.5}$ and PM_{10} emissions by multiplying the generation predicted for each IPM plant type (ultrasupercritical coal without carbon capture and storage, combined cycle, combustion turbine, etc.) by a type-specific empirical emission factor derived from the 2016 National Emissions Inventory (NEI) and other data sources. The emission factors reflect the fuel type (including coal rank), FGD controls, and state emission limits for each plant type, where applicable.

Comparing emissions projected under Option A to those projected for the baseline provides an assessment of the changes in air emissions resulting from changes in the profile of electricity generation under the final rule.[69] EPA used seven run years, shown in Table 8-1, to represent the 2021-2047 period of analysis.

Table 8-1: IPM Run Years

IPM Run Year	Years Represented
2021	2021
2023	2022-2023
2025	2024-2027
2030	2028-2032
2035	2033-2037
2040	2038-2042
2045	2043-2047

Source: U.S. EPA, 2018b

As part of its analysis of non-water quality environmental impacts, EPA developed separate estimates of changes in energy requirements for operating wastewater treatment systems and ash handling systems, and changes in transportation needed to landfill solid waste and CCR (see *Supplemental TDD* for details; U.S. EPA, 2020g). EPA estimated NO_X, SO_2, and CO_2 emissions associated with changes in energy requirements to power wastewater treatment systems by multiplying plant-specific changes in electricity consumption by plant- or North American Electric Reliability Corporation (NERC)-specific emission factors obtained from

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[69] While EPA only ran IPM for the final rule (Option A), the Agency extrapolated the benefits estimated using these IPM outputs to Options B and C to provide insight on the potential air quality-related effects of the other regulatory options. See Section 8.4 for details.

IPM for each run year. EPA estimated air emissions associated with changes in transportation by multiplying the number of miles traveled by average emission factors.

Table 8-2 summarizes the estimated changes in emissions associated with changes in power requirements to operate treatment systems and with the transportation of CCR and solid waste under the regulatory options. EPA estimates that changes in power requirements and transportation would result in a decrease in emissions under Options A and B, and an increase in emissions under Option C. These values reflect full technology implementation under the regulatory options, which is projected to occur by the end of 2028.[70]

Table 8-2: Estimated Changes in Air Pollutant Emissions Due to Increase in Power Requirements and Trucking at Steam Electric Power Plants 2021-2047, Compared to Baseline

Regulatory Option	CO_2 (Million Tons/Year)[a]	NOx (Thousand Tons/Year)[a]	SO_2 (Thousand Tons/Year)[a]	Primary $PM_{2.5}$ (Thousand Tons/Year)[a]
Option D[b]	*-0.073*	*-0.049*	*-0.082*	*Not estimated*
Power Requirements				
Option A (Final Rule)	-0.023	-0.013	-0.016	Not estimated
Option B	-0.020	-0.012	-0.015	Not estimated
Option C	0.180	0.079	0.063	Not estimated
Transportation				
Option A (Final Rule)	-0.0098	-0.0090	-0.000082	Not estimated
Option B	-0.0098	-0.0090	-0.000082	Not estimated
Option C	-0.0080	-0.0073	-0.000067	Not estimated

a. Values rounded to two significant figures. Negative values indicate a reduction in emissions and positive values indicate an increase in emissions.

b. Option D corresponds to the proposed Option 1. EPA did not reanalyze this option for the final rule. All results shown for Option D are based on the 2019 analysis, as detailed in the 2019 *BCA* (U.S. EPA, 2019a). As such, the values do not reflect changes in the baseline, plant universe, and other analytical inputs for the analysis of Options A, B, and C. Values are the net total change associated with power requirements and transportation (see Table 7-3 in the 2019 *Supplemental TDD* [U.S. EPA, 2019k])

Source: U.S. EPA Analysis, 2020

Table 8-3 and Table 8-4 summarize the estimated changes in pollutant emissions from electricity generation under the final rule (*i.e.*, Option A).[71] As shown in the two tables, projected changes in the profile of electricity generation under Option A, compared to the baseline, generally lead to increased pollutant emissions starting with the 2023 run year. Within this general trend, there are a few run years within the period of analysis when emissions of NO_X (in 2035 and 2040), SO_2 (in 2023, 2035 and 2040), and primary $PM_{2.5}$ (in 2040) decrease relative to the baseline. These changes in air emissions reflect the differences in emissions factors for coal as compared to other fuels. As presented in the *RIA* (U.S. EPA, 2020d; see Section 5.2), IPM projects increases in electricity generation from coal as a result of the final rule (approximately 0.6 percent in 2030), while decreases are projected for generation from other fuels or energy sources, specifically natural gas and renewables.

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[70] For the purpose of this analysis, EPA developed a time profile of air emissions changes based on plants' estimated technology implementation years during the period of 2021 through 2028.

[71] EPA did not run IPM for Options B and C.

Table 8-3: Estimated Changes in Annual CO_2, NO_X, SO_2, and Primary $PM_{2.5}$ Emissions Due to Changes in Electricity Generation Profile, Compared to Baseline

Regulatory Option	Year	CO_2 (Million Tons/Year)[a]	NOx (Thousand Tons/Year)[a]	SO_2 (Thousand Tons/Year)[a]	Primary $PM_{2.5}$ (Thousand Tons/Year)[a]
Option A (Final Rule)	2021	-0.079	-0.25	-1.4	-0.028
	2023	2.9	3.0	-2.6	0.45
	2025	2.2	1.6	-0.70	0.91
	2030	2.7	0.69	1.7	0.48
	2035	0.88	-0.57	1.8	0.81
	2040	1.0	-1.6	-2.9	-0.22
	2045	2.8	0.15	0.92	0.44

a. Values rounded to two significant figures. Negative values indicate a reduction in emissions and positive values indicate an increase in emissions.

Source: U.S. EPA Analysis, 2020; See Chapter 5 in RIA for details on IPM (U.S. EPA, 2020d).

Table 8-4: Estimated Changes in Annual Primary PM_{10}, Hg and HCl Emissions Due to Changes in Electricity Generation Profile, Compared to Baseline

Regulatory Option	Year	Primary PM_{10} (Thousand Tons/Year)[a]	Hg (Tons/Year)[a]	HCl (Tons/Year)[a]
Option A (Final Rule)	2021	0.0035	0.0043	-0.41
	2023	0.58	0.015	17
	2025	1.1	0.015	15
	2030	0.43	0.010	24
	2035	0.80	0.0030	11
	2040	-0.47	0.0027	14
	2045	0.28	0.0018	13

a. Values rounded to two significant figures. Negative values indicate a reduction in emissions and positive values indicate an increase in emissions.

Source: U.S. EPA Analysis, 2020; See Chapter 5 in RIA for details on IPM (U.S. EPA, 2020d).

The rest of this chapter quantifies benefits associated with changes in emissions of CO_2, SO_2, NO_X, and primary $PM_{2.5}$. Table 8-5 presents the net changes in emissions of these four pollutants for the final rule across the three mechanisms compared to baseline. The largest effect on projected air emissions is due to the change in the emissions profile of electricity generation at the market level.

Table 8-5: Estimated Net Changes in Air Pollutant Emissions Due to Changes in Power Requirements, Trucking, and Electricity Generation Profile, Compared to Baseline

Regulatory Option	Year	CO_2 (Million Tons/Year)[a]	NOx (Thousand Tons/Year)[a]	SO_2 (Thousand Tons/Year)[a]	Primary $PM_{2.5}$ (Thousand Tons/Year)[a]
Option A (Final Rule)	2021	-0.088	-0.25	-1.4	-0.028
	2023	2.9	2.9	-2.6	0.45
	2025	2.2	1.6	-0.73	0.91
	2030	2.6	0.67	1.6	0.48
	2035	0.85	-0.59	1.7	0.81
	2040	0.97	-1.6	-3.0	-0.22
	2045	2.8	0.12	0.90	0.44

a. Values rounded to two significant figures. Negative values indicate a reduction in emissions and positive values indicate an increase in emissions.

Table 8-5: Estimated Net Changes in Air Pollutant Emissions Due to Changes in Power Requirements, Trucking, and Electricity Generation Profile, Compared to Baseline

Regulatory Option	Year	CO_2 (Million Tons/Year)[a]	NOx (Thousand Tons/Year)[a]	SO_2 (Thousand Tons/Year)[a]	Primary $PM_{2.5}$ (Thousand Tons/Year)[a]

Source: U.S. EPA Analysis, 2020

8.2 Climate Change Benefits

8.2.1 Data and Methodology

EPA estimated the monetary value of CO_2 emission changes using a measure of the domestic social cost of carbon (SC-CO_2). The SC-CO_2 is a metric that estimates the monetary value of projected impacts associated with marginal changes in CO_2 emissions in a given year. It includes a wide range of anticipated climate impacts, such as net changes in agricultural productivity and human health, property damage from increased flood risk, and changes in energy system costs, such as reduced costs for heating and increased costs for air conditioning. It is used to assess the change in damages as a result of regulatory actions (*e.g.*, benefits of rulemakings that lead to an incremental reduction in cumulative global CO_2 emissions). The SC-CO_2 estimates used in this analysis focus on the projected impacts of climate change that are anticipated to directly occur within U.S. borders.

The SC-CO_2 estimates used in this analysis are interim values developed under EO 13783 for use in regulatory analyses until an improved estimate of the impacts of climate change to the U.S. can be developed based on the best available science and economics. EO 13783 directed agencies to ensure that estimates of the social cost of greenhouse gases used in regulatory analyses “are based on the best available science and economics” and are consistent with the guidance contained in OMB Circular A-4, “including with respect to the consideration of domestic versus international impacts and the consideration of appropriate discount rates” (EO 13783, Section 5(c)). In addition, EO 13783 withdrew the technical support documents (TSDs) used in the benefits analysis of the 2015 rule for describing the global social cost of greenhouse gas estimates developed under the prior Administration as no longer representative of government policy.

Regarding the two analytical considerations highlighted in EO 13783 – how best to consider domestic versus international impacts and appropriate discount rates – current guidance in OMB Circular A-4 is as follows. Circular A-4 states that analysis of economically significant proposed and final regulations “should focus on benefits and costs that accrue to citizens and residents of the United States.” (OMB, 2003) EPA follows this guidance by adopting a domestic perspective in the central analysis. Regarding discount rates, Circular A-4 states that regulatory analyses “should provide estimates of net benefits using both 3 percent and 7 percent.” (OMB, 2003) The 7 percent rate is intended to represent the average before-tax rate of return to private capital in the U.S. economy. The 3 percent rate is intended to reflect the rate at which society discounts future consumption, which is particularly relevant if a regulation is expected to affect private consumption directly. EPA follows this guidance by presenting estimates based on both 3 and 7 percent discount rates in the main analysis. See *Appendix I* for a discussion of the modeling steps involved in estimating the domestic SC-CO_2 estimates based on these discount rates. These SC-CO_2 estimates developed under EO 13783 and presented below will be used in regulatory analysis until more comprehensive domestic estimates are developed, which would take into consideration recent recommendations from the National Academies of Sciences and Medicine (2017) to further update the current methodology to ensure that the SC-CO_2 estimates reflect the best available science.

Table 8-6T presents the average domestic SC-CO_2 estimate across all of the integrated assessment model runs used to estimate the SC-CO_2 for each discount rate for the years 2015 to 2050.[72] As with the global SC-CO_2 estimates, the domestic SC-CO_2 increases over time because future emissions are expected to produce larger incremental damages as economies grow and physical and economic systems become more stressed in response to climate change.

EPA estimated the dollar value of the CO_2-related effects for each analysis year between 2021 and 2047 by applying the SC-CO_2 estimates, shown in Table 8-6T, to the estimated changes in CO_2 emissions in the corresponding year under the regulatory options. EPA then calculated the present value and annualized benefits from the perspective of 2020 by discounting each year-specific value to the year 2020 using the same 3 percent and 7 percent discount rates.

Table 8-6: Interim Domestic Social Cost of Carbon Values (2018$/Metric Tonne CO_2)

Year	3% Discount Rate, Average	7% Discount Rate, Average
2020	$7	$1
2025	$7	$1
2030	$8	$1
2035	$9	$2
2040	$10	$2
2045	$10	$2
2050	$11	$2

Note: These SC-CO_2 values are stated in $/metric tonne CO_2 and rounded to the nearest dollar (1 metric tonne equals 1.102 short tons). The estimates vary depending on the year of CO_2 emissions and are defined in real terms, i.e., adjusted for inflation using the GDP implicit price deflator. Values were updated from 2016 dollars to 2018 dollars using the GDP deflator (1.030). EPA interpolated annual values for intermediate years.

Source: U.S. EPA Analysis, 2020 based on U.S. EPA (2019i)

The limitations and uncertainties associated with the SC-CO_2 analysis, which were discussed in the 2015 and 2019 *BCAs* (U.S. EPA, 2015a, 2019a), likewise apply to the domestic SC-CO_2 estimates presented in this chapter. Some uncertainties are captured within the analysis, as discussed in *Appendix I*, while other areas of uncertainty have not yet been quantified in a way that can be modeled. For example, limitations include the incomplete way in which the integrated assessment models capture catastrophic and non-catastrophic impacts, their incomplete treatment of adaptation and technological change, the incomplete way in which inter-regional and intersectoral linkages are modeled, uncertainty in the extrapolation of damages to high temperatures, and inadequate representation of the relationship between the discount rate and uncertainty in economic growth over long time horizons. The science incorporated into these models understandably lags behind the most recent research, and the limited amount of research linking climate impacts to economic damages makes this comprehensive global modeling exercise even more difficult. These individual limitations and uncertainties do not all work in the same direction in terms of their influence on the SC-CO_2 estimates. In accordance with guidance in OMB Circular A-4 on the treatment of uncertainty, *Appendix I* provides a detailed discussion of the ways in which the modeling underlying the development of the SC-CO_2

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[72] The SC-CO_2 estimates rely on an ensemble of three integrated assessment models (IAMs): Dynamic Integrated Climate and Economy (DICE) 2010; Climate Framework for Uncertainty, Negotiation, and Distribution (FUND) 3.8; and Policy Analysis of the Greenhouse Gas Effect (PAGE) 2009.

estimates used in this BCA addressed quantified sources of uncertainty and presents a sensitivity analysis to show consideration of the uncertainty surrounding discount rates over long time horizons.

Recognizing the limitations and uncertainties associated with estimating the SC-CO_2, the research community has continued to explore opportunities to improve SC-CO_2 estimates. Notably, the National Academies of Sciences, Engineering, and Medicine conducted a multidiscipline, multi-year assessment to examine potential approaches, along with their relative merits and challenges, for a comprehensive update to the current methodology. The task was to ensure that the SC-CO_2 estimates that are used in Federal analyses reflect the best available science, focusing on issues related to the choice of models and damage functions, climate science modeling assumptions, socioeconomic and emissions scenarios, presentation of uncertainty, and discounting. In January 2017, the Academies released their final report, "Assessing Approaches to Updating the Social Cost of Carbon," and recommended specific criteria for future updates to the SC-CO_2 estimates, a modeling framework to satisfy the specified criteria, and both near-term updates and longer-term research needs pertaining to various components of the estimation process (National Academies of Sciences & Medicine, 2017).

The Academies' 2017 report also discussed the challenges in developing domestic SC-CO_2 estimates, noting that current integrated assessment models do not model all relevant regional interactions – *i.e.*, how climate change impacts in other regions of the world could affect the United States, through pathways such as global migration, economic destabilization, and political destabilization. The Academies concluded that it "is important to consider what constitutes a domestic impact in the case of a global pollutant that could have international implications that impact the United States. More thoroughly estimating a domestic SC-CO_2 would therefore need to consider the potential implications of climate impacts on, and actions by, other countries, which also have impacts on the United States." (National Academies of Sciences & Medicine, 2017, pg. 12-13). In addition to requiring reporting of impacts at a domestic level, Circular A-4 states that when an agency "evaluate[s] a regulation that is likely to have effects beyond the borders of the United States, these effects should be reported separately" (OMB, 2003; page 15). This guidance is relevant to the valuation of damages from CO_2 and other greenhouse gases (GHGs), given that GHGs contribute to damages around the world independent of the country in which they are emitted. Therefore, in accordance with this guidance in OMB Circular A-4, *Appendix I* presents the global climate benefits from this final rule using global SC-CO_2 estimates based on both 3 and 7 percent discount rates. EPA did not quantitatively project the full impact of the final rule on international trade and the location of production, so it is not possible to present analogous estimates of international costs resulting from the regulatory options. However, to the extent that the electricity market analysis endogenously models international electricity and natural gas trade (see *RIA*, Chapter 5; U.S. EPA, 2020d), and to the extent that affected firms have some foreign ownership, some of the costs accruing to entities outside U.S. borders is captured in the technology implementation costs presented in the *RIA* (U.S. EPA, 2020d).

8.2.2 Results

Table 8-7 shows the estimated monetary value of the estimated changes in CO_2 emissions in each of several selected years for Option A, the final rule. Negative values indicate forgone benefits as compared to the baseline.

Table 8-7: Estimated Domestic Climate Benefits from Changes in CO_2 Emissions for Selected Years under the Final Rule, Compared to Baseline (Millions of 2018$)

Regulatory Option	Year	3% Discount Rate[a]	7% Discount Rate[a]
Option A (Final Rule)	2021	$0.55	$0.08
	2025	-$15	-$2.4
	2030	-$19	-$3.3
	2035	-$6.7	-$1.3
	2040	-$8.4	-$1.7
	2045	-$26	-$5.3
	2047	-$26	-$5.6

a. Values rounded to two significant figures. Negative values indicate forgone benefits (*i.e.*, the number of avoided cases under the final rule is smaller than in the baseline).

Source: U.S. EPA Analysis, 2020

Table 8-8 shows the total annualized monetary values associated with changes in CO_2 emissions for the final rule by category of emissions. EPA annualized monetary value estimates to enable consistent reporting across benefit categories (*e.g.*, benefits from improvement in water quality). The annualized values are -$14 million and -$2.3 million, using discount rates of 3 and 7 percent, respectively. The values are negative, indicating that the final rule results in forgone benefits when compared to the baseline. The vast majority of the forgone benefits arise from changes in the profile of electricity generation.

Table 8-8: Estimated Total Annualized Domestic Climate Benefits from Changes in CO_2 Emissions under the Final Rule, Compared to Baseline (Millions of 2018$)

Regulatory Option	Category of Air Emissions	3% Discount Rate[a]	7% Discount Rate[a]
Option A (Final Rule)	Electricity Generation	-$14	-$2.3
	Trucking	$0.07	$0.01
	Energy use	$0.18	$0.03
	Total	**-$14**	**-$2.3**

a. Values rounded to two significant figures. Negative values indicate forgone benefits (*i.e.*, the number of avoided cases under the final rule is smaller than in the baseline).

Source: U.S. EPA Analysis, 2020

8.3 Human Health Benefits

8.3.1 Data and Methodology

As summarized in Table 8-5, the final rule is estimated to influence the level of pollutants emitted in the atmosphere that adversely affect human health, including directly emitted $PM_{2.5}$, as well as SO_2 and NO_X, which are both precursors to ambient $PM_{2.5}$. NO_X emissions are also a precursor to ambient ground-level ozone. The change in emissions in turn alters the ambient concentrations, which in turn leads to changes in population exposure. In this document we estimate changes in the human health impacts associated with $PM_{2.5}$ and ozone.[73]

This section summarizes EPA's approach to estimating the incidence and economic value of the potential $PM_{2.5}$ and ozone-related benefits estimated for this final rule. The approach entails two major steps: (1) Developing spatial fields of air quality across the U.S. using nationwide photochemical modeling and related analyses; and (2) Using these spatial fields in BenMAP-CE to quantify the benefits under Option A as compared to the baseline.

Under this approach, EPA used IPM projections of EGU air emissions under the baseline and final rule. EPA then adjusted outputs from this analysis to account for the effects of incremental emissions from transportation and energy use, and to estimate the benefits of Options B and C. See Section 8.4 for a description of the methodology for these estimates.

8.3.1.1 Air Quality Modeling Methodology

To create annual $PM_{2.5}$ and ozone spatial fields representing the baseline and Option A, EPA leveraged available photochemical modeling outputs that were created as part of the *Regulatory Impact Analysis for the Repeal of the Clean Power Plan, and the Emission Guidelines for Greenhouse Gas Emissions from Existing Electric Utility Generating Units* (U.S. EPA, 2019i), also referred to the Affordable Clean Energy (ACE) rule. These $PM_{2.5}$ and ozone spatial fields were used as input to BenMAP-CE which, in turn, was used to quantify the benefits from this final rule. The analysis supporting this rule used outputs from several full-scale photochemical model simulations.

EPA prepared spatial fields of air quality for the baseline and the final rule for each of the following health-impact metrics: annual mean $PM_{2.5}$, May through September seasonal average 8-hour daily maximum (MDA8) ozone, and April through October seasonal average 1-hour daily maximum (MDA1) ozone. The EGU emissions for the baseline and the final rule, consisting of total NO_X, SO_2, and primary $PM_{2.5}$ emissions summarized by year, state, and generation type, were obtained from the outputs of the corresponding IPM runs, as described in Section 8.1 of this document and Chapter 5 of the *RIA* (U.S. EPA, 2020d). As such, the spatial fields do not account for changes in emissions associated with power requirements to operate treatment systems or transportation. See Section 8.5 regarding limitations and uncertainty associated with this analysis.

The photochemical model simulations as well as the basic methodology for determining air quality changes are the same as those used in the ACE RIA. *Appendix J* provides an overview of the air quality modeling and the methodologies EPA used to develop spatial fields of annual $PM_{2.5}$ and seasonal ozone concentrations. The appendix also provides selected figures showing the geographical and temporal distribution of air quality changes. Additional information on the air quality modeling platform (inputs and set-up), model performance evaluation for $PM_{2.5}$ and ozone, emissions processing for this analysis, and additional details and numerical examples of the methodologies for developing $PM_{2.5}$ and ozone spatial fields are available in U.S. EPA (2019i; Chapter 8) .

EPA used air quality modeling to estimate health benefits associated with changes in particulate matter and ozone concentrations that may occur because of the final rule relative to the baseline, with the air quality

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[73] Ambient concentrations of both SO_2 and NO_X also pose health risks independent of $PM_{2.5}$ and ozone, though EPA does not quantify these impacts in this analysis (U.S. EPA, 2016a, 2017c)

modeling baseline including emissions from all sources. Consequently, in addition to rules and economic conditions included in IPM, the baseline for this analysis included emissions from, and rules for, non-EGU point sources, on-road vehicles, non-road mobile equipment and marine vessels.[74] While the air quality model includes a range of pollution sources, contributions from non-EGU point sources, on-road vehicles, non-road mobile equipment and marine vessels are held constant in this analysis, and the only changes are those associated with the projected impacts of the final rule on the profile of electricity generation and EGU emissions, as compared to the baseline. The modeled air quality changes do not include other potential effects of the final rule, such as changes in power requirements to run treatment systems or changes in CCR transportation, which were estimated separately as described in section 8.1 and were found to be negligible as described in section 8.4.

8.3.1.2 $PM_{2.5}$ and Ozone Related Health Impacts

EPA estimated the benefits of the final rule using the open-source environmental Benefits Mapping and Analysis Program—Community Edition (BenMAP-CE) (Sacks *et al.*, 2018). The procedure for calculating and valuing air pollution-related impacts is described in detail in Fann *et al.* (2018), Sacks *et al.* (2018), and U.S. EPA (2012).

The BenMAP-CE tool uses health impact functions to quantify excess cases of air pollution-attributable premature deaths and illnesses. When used to quantify $PM_{2.5}$- or ozone-related effects, the functions combine an effect estimates (*i.e.*, the β coefficients) from epidemiological studies, which portray the relationship between a change in air quality and a health effect, such as mortality, with estimated $PM_{2.5}$ or ozone concentrations (supplied using the model simulations described above), population data, and baseline death rates for each county in each year. The Agency estimates the incidence of air pollution effects for those health endpoints which the relevant Integrated Science Assessment (ISA) classified as either causal or likely-to-be-causal. Table 8-9 reports the effects EPA quantified (and monetized) and those the Agency did not quantify.[75]

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[74] The air quality modeling techniques used for this analysis reflect non-EGU emissions as of 2023, so implementation or effects of any changes in non-EGU emissions expected to occur after 2023 are not accounted for in this analysis. However, the effect of non-EGU emissions on changes in pollution concentrations due to the final rule is likely to be small.

[75] EPA is evaluating the adequacy of the PM and O_3 National Ambient Air Quality Standards (NAAQS). Once EPA promulgates final PM and O_3 NAAQS, the Agency will revisit its approach for estimating benefits for each pollutant.

Table 8-9: Human Health Effects of Ambient $PM_{2.5}$ and Ozone

Category	Effect	Effect Quantified	Effect Monetized	More Information
Premature mortality from exposure to $PM_{2.5}$	Adult premature mortality based on cohort study estimates and expert elicitation estimates (age >25 or age >30)	✓	✓	PM ISA
	Infant mortality (age <1)	✓	✓	PM ISA
Morbidity from exposure to $PM_{2.5}$	Non-fatal heart attacks (age > 18)	✓	✓	PM ISA
	Hospital admissions—respiratory (all ages)	✓	✓	PM ISA
	Hospital admissions—cardiovascular (age >20)	✓	✓	PM ISA
	Emergency room visits for asthma (all ages)	✓	✓	PM ISA
	Acute bronchitis (age 8-12)	✓	✓	PM ISA
	Lower respiratory symptoms (age 7-14)	✓	✓	PM ISA
	Upper respiratory symptoms (asthmatics age 9-11)	✓	✓	PM ISA
	Exacerbated asthma (asthmatics age 6-18)	✓	✓	PM ISA
	Lost work days (age 18-65)	✓	✓	PM ISA
	Minor restricted-activity days (age 18-65)	✓	✓	PM ISA
	Chronic Bronchitis (age >26)	—	—	PM ISA[a]
	Emergency room visits for cardiovascular effects (all ages)	—	—	PM ISA[a]
	Strokes and cerebrovascular disease (age 50-79)	—	—	PM ISA[a]
	Other cardiovascular effects (e.g., other ages)	—	—	PM ISA[b]
	Other respiratory effects (e.g., pulmonary function, non-asthma ER visits, non-bronchitis chronic diseases, other ages and populations)	—	—	PM ISA[b]
	Reproductive and developmental effects (e.g., low birth weight, pre-term births)	—	—	PM ISA[b,c]
	Cancer, mutagenicity, and genotoxicity effects	—	—	PM ISA[b,c]
Mortality from exposure to ozone	Premature mortality based on short-term study estimates (all ages)	✓	✓	Ozone ISA
	Premature mortality based on long-term study estimates (age 30–99)	✓	✓	Ozone ISA[a]
Morbidity from exposure to ozone	Hospital admissions—respiratory causes (age > 65)	✓	✓	Ozone ISA
	Emergency department visits for asthma (all ages)	✓	✓	Ozone ISA
	Exacerbated asthma (asthmatics age 6-18)	✓	✓	Ozone ISA
	Minor restricted-activity days (age 18–65)	✓	✓	Ozone ISA
	School absence days (age 5–17)	✓	✓	Ozone ISA
	Decreased outdoor worker productivity (age 18–65)	—	—	Ozone ISA[a]
	Other respiratory effects (e.g., premature aging of lungs)	—	—	Ozone ISA[b]
	Cardiovascular and nervous system effects	—	—	Ozone ISA[b]
	Reproductive and developmental effects	—	—	Ozone ISA[b,c]

a. EPA assesses these benefits qualitatively due to data and resource limitations for this analysis. In other analyses EPA quantified these effects as a sensitivity analysis.

b. EPA assesses these benefits qualitatively because of insufficient confidence in available data or methods.

c. EPA assesses these benefits qualitatively because current evidence is only suggestive of causality or there are other significant concerns over the strength of the association.

Source: U.S. EPA Analysis, 2020

After having quantified $PM_{2.5}$- and ozone-attributable cases of premature death and illness, EPA estimated the economic value of these cases using WTP and COI measures. For this analysis, EPA used version 1.5.0.4 of BenMAP-CE (March 2019 release). The Appendix to the BenMAP-CE user manual and the RIA for the

Particulate Matter National Ambient Air Quality Standards each detail the sources of the above input parameters (U.S. EPA, 2012, 2018a).

EPA estimated the number of $PM_{2.5}$-attributable premature deaths using effect estimates from two epidemiology studies examining two large population cohorts: the American Cancer Society (Krewski *et al.*, 2009) and the Harvard Six Cities (Lepeule *et al.*, 2012) cohorts. Consistent with the ACE RIA (U.S. EPA, 2019i), EPA reports the estimated number of $PM_{2.5}$-attributable deaths according to alternative $PM_{2.5}$ concentration cutpoints. This approach allows readers to determine the portion of the population exposed to annual mean $PM_{2.5}$ levels at or above different concentrations. However, EPA does not view these concentration cutpoints as thresholds below which there are no quantifiable human health impacts attributable to $PM_{2.5}$. EPA reports the ozone-attributable deaths as a range reflecting the intensity of the relationship between ozone levels and health effects as reflected in concentration-response parameters from R. L. Smith *et al.* (2009) on the low end to Jerrett *et al.*, 2009 on the high end.

Projected impacts of the final rule show both decreased and increased levels of $PM_{2.5}$ and ozone, depending on the year and location, compared to the baseline (see maps in *Appendix J* for details). Some portion of the air quality and health benefits from the final rule occur in areas not attaining the $PM_{2.5}$ or Ozone National Ambient Air Quality Standards (NAAQS), the requirements of which should be accounted for in the baseline. The analysis does not account for possible interactions between NAAQS compliance and the final rule, which introduces uncertainty into the benefits (and forgone benefits) estimates. If the final rule increases or decreases primary $PM_{2.5}$, SO_2 and NO_X emissions and consequentially $PM_{2.5}$ and/or ozone concentrations, these changes may affect compliance with existing NAAQS standards and subsequently affect the actual benefits (and forgone benefits) of the final rule. For example, in the case of areas that do not meet the NAAQS that see decreased concentrations of $PM_{2.5}$ or ozone, states may be able to avoid applying certain other measures to assure NAAQS attainment. As a result, there would be avoided costs and the $PM_{2.5}$ and ozone health and ecological benefits of the final rule would likely be lessened. In areas not attaining the NAAQS where $PM_{2.5}$ or ozone concentrations may increase due to the final rule, states may need to identify additional approaches to reduce emissions from local sources relative to the baseline, thus mitigating any increased $PM_{2.5}$ and ozone concentrations. In this case, the health benefits would be higher and there would be additional social costs associated with these additional approaches.

8.3.2 Results

EPA reports below the estimated number of reduced or increased $PM_{2.5}$ and ozone-related premature deaths and illnesses in each year for Option A, the final rule, relative to the baseline along with the 95% confidence interval (see Table 8-10). The number of reduced or increased estimated deaths and illnesses under the final rule are calculated from the sum of individual reduced mortality and illness risk across the population in a given year. Table 8-11 provides the estimated number of avoided or increased $PM_{2.5}$- related premature deaths calculated using different approaches to help the reader determine the fraction of $PM_{2.5}$ attributable deaths occurring at lower ambient concentrations. Table 8-12 summarizes the dollar value of these impacts for the final rule across all $PM_{2.5}$ and ozone-related premature deaths and illnesses, using alternative approaches to representing and quantifying $PM_{2.5}$ mortality risk effects. Because total benefits are a function of both increases and decreases in $PM_{2.5}$ and ozone exposures depending on the year of analysis, the percentage of total benefits attributable to reducing $PM_{2.5}$ exposure may, for example, outweigh the percentage of foregone benefits attributable to increasing ozone exposure during one year, while the percentage of total forgone benefits of increasing $PM_{2.5}$ exposure may outweigh the percentage of benefits attributable to decreasing ozone exposure in another year.

The alternative approaches to quantifying and presenting mortality risk effects include both different means for quantifying expected impacts using concentration-response functions over the entire domain of exposure (*i.e.*, the no-threshold model) along with different means of presenting impacts by limiting consideration to only those impacts at exposures above the lowest measured level (LML) or above the NAAQS (Table 8-13). The estimated number of deaths above and below the LML varies considerably according to the epidemiology study used to estimate risk. Thus, for four out of seven years analyzed, EPA estimated a larger fraction of $PM_{2.5}$-related deaths above the LML of the Krewski *et al.* (2009) study than the Lepeule *et al.*, 2012 study as shown in Table 8-13. Likewise, EPA estimated a greater percentage of $PM_{2.5}$-related deaths below the LML of the Lepeule *et al.* (2012) study than the Krewski *et al.* (2009) study for four out of seven years analyzed. Table 8-13 also shows a very small percentage of $PM_{2.5}$-related premature deaths occurring above the NAAQS in any future year using either of these two studies.

Table 8-10: Estimated Avoided $PM_{2.5}$ and Ozone-Related Premature Deaths and Illnesses by Year for the Final Rule, Compared to Baseline (95% Confidence Interval)

Category	Basis	2021[a]	2023[a]	2025[a]	2030[a]	2035[a]	2040[a]	2045[a]
Avoided premature death among adults[b]								
$PM_{2.5}$	Krewski et al. (2009)	15 (10 to 20)	8 (6 to 11)	3 (2 to 4)	-4 (-5 to -3)	-11 (-15 to -8)	27 (18 to 36)	-8 (-11 to -5)
	Lepeule et al. (2012)	34 (17 to 50)	19 (10 to 29)	7 (3 to 11)	-9 (-14 to -5)	-25 (-38 to -13)	61 (30 to 91)	-18 (-27 to -9)
Ozone (O_3)	Smith et al. (2009)	1 (0 to 1)	-1 (-2 to 0)	-1 (-1 to 0)	0 (0 to 0)	0 (0 to 0)	2 (1 to 3)	1 (0 to 1)
	Jerrett et al. (2009)	3 (1 to 5)	-3 (-6 to -1)	-3 (-6 to -1)	0 (0 to 1)	0 (0 to 1)	7 (2 to 11)	2 (1 to 4)
$PM_{2.5}$-related non-fatal heart attacks among adults								
Peters et al. (2001)		15 (4 to 27)	10 (2 to 17)	5 (1 to 8)	-6 (-10 to -1)	-15 (-26 to -4)	26 (6 to 45)	-12 (-21 to -3)
Pooled estimate		2 (1 to 4)	1 (0 to 3)	0 (0 to 1)	-1 (-2 to 0)	-2 (-4 to -1)	3 (1 to 7)	-1 (-4 to 0)
All other morbidity effects								
Hospital admissions—cardiovascular ($PM_{2.5}$)		4 (2 to 7)	2 (1 to 4)	1 (0 to 2)	-1 (-2 to -1)	-4 (-6 to -3)	6 (3 to 12)	-3 (-5 to -2)
Hospital admissions—respiratory ($PM_{2.5}$ & O_3)		5 (-2 to 10)	2 (-1 to 3)	0 (0 to 1)	-2 (-2 to -1)	-5 (-6 to -2)	7 (-3 to 13)	-5 (-5 to -4)
ER visits for asthma (PM2.5 & O_3)		11 (-2 to 28)	-3 (-27 to 10)	-6 (-22 to 2)	-1 (-5 to 7)	-2 (-10 to 11)	28 (-4 to 72)	4 (-7 to 23)
Exacerbated asthma ($PM_{2.5}$ & O_3)		2100 (-1500 to 5100)	-1700 (-5100 to 2700)	-1800 (-4900 to 2100)	630 (-960 to 1900)	350 (-1300 to 1700)	5100 (-3600 to 12000)	1400 (-1900 to 4000)
Minor restricted-activity days ($PM_{2.5}$ & O_3)		13000 (9500 to 17000)	3100 (1900 to 4300)	-1300 (-3200 to 560)	-1600 (-1900 to -1300)	-5300 (-5700 to -4900)	26000 (18000 to 34000)	-1200 (-2400 to -18)
Acute bronchitis ($PM_{2.5}$)		18 (-4 to 41)	16 (-4 to 36)	7 (-2 to 15)	-6 (-13 to 1)	-14 (-30 to 3)	36 (-9 to 81)	-9 (-21 to 2)
Upper resp. symptoms ($PM_{2.5}$)		330 (60 to 600)	290 (53 to 530)	120 (21 to 220)	-100 (-190 to -19)	-250 (-450 to -45)	660 (120 to 1200)	-170 (-310 to -31)
Lower resp. symptoms ($PM_{2.5}$)		230 (89 to 380)	210 (78 to 330)	84 (32 to 140)	-73 (-120 to -28)	-170 (-280 to -65)	460 (180 to 750)	-120 (-190 to -45)
Lost work days ($PM_{2.5}$)		1700 (1400 to 1900)	1300 (1100 to 1500)	470 (400 to 500)	-540 (-620 to -450)	-1100 (-1300 to -970)	3100 (2600 to 3500)	-820 (-940 to -690)

Table 8-10: Estimated Avoided $PM_{2.5}$ and Ozone-Related Premature Deaths and Illnesses by Year for the Final Rule, Compared to Baseline (95% Confidence Interval)

Category	Basis	2021[a]	2023[a]	2025[a]	2030[a]	2035[a]	2040[a]	2045[a]
Avoided premature death among adults[b]								
School absence days (O_3)		1000 (370 to 2300)	-1300 (-2900 to -460)	-1300 (-2800 to -450)	490 (170 to 1100)	430 (150 to 960)	2600 (930 to 5800)	1100 (370 to 2300)

a. Values rounded to two significant figures. Negative values indicate forgone benefits (*i.e.*, the number of avoided cases under the final rule is smaller than in the baseline). Lower bound of confidence interval represents the 95% confidence estimate that is lower in value than the point estimate, while upper bound represents the estimate that is higher in value than the point estimate.

b. EPA also quantified changes in premature infant mortality from exposure to $PM_{2.5}$ but the estimated change was less than 1 for all years analyzed.

Source: U.S. EPA Analysis, 2020

Table 8-11: Estimated Avoided $PM_{2.5}$ and Ozone-Related Premature Deaths and Illnesses for the Final Rule, Compared to Baseline, Using Alternative Approaches to Quantifying Avoided $PM_{2.5}$-Attributable Deaths (95% Confidence Interval)

Category	Basis	2021	2023	2025	2030	2035	2040	2045
Avoided premature death among adults								
Log-linear no-threshold model	Krewski et al. (2009)	15 (10 to 20)	8 (6 to 11)	3 (2 to 4)	-4 (-5 to -3)	-11 (-15 to -8)	27 (18 to 36)	-8 (-11 to -5)
	Lepeule et al. (2012)	34 (17 to 50)	19 (10 to 29)	7 (3 to 11)	-9 (-14 to -5)	-25 (-38 to -13)	61 (30 to 91)	-18 (-27 to -9)
Quantifying effect of $PM_{2.5}$ above the LML in each study	Krewski et al. (2009)	13 (9 to 17)	9 (6 to 13)	4 (3 to 6)	0 (0 to 0)	-9 (-12 to -6)	26 (17 to 34)	-6 (-8 to -4)
	Lepeule et al. (2012)	18 (13 to 40)	5 (3 to 8)	-1 (-2 to -1)	-11 (-16 to -5)	-21 (-31 to -10)	38 (19 to 56)	-16 (-24 to -8)

a. Values rounded to two significant figures. Negative values indicate forgone benefits (*i.e.*, the number of avoided cases under the final rule is smaller than in the baseline). Lower bound of confidence interval represents the 95% confidence estimate that is lower in value than the point estimate, while upper bound represents the estimate that is higher in value than the point estimate.

Source: U.S. EPA Analysis, 2020

Table 8-12: Estimated Economic Value of Avoided PM2.5 and Ozone-Attributable Deaths and Illnesses for the Final Rule, Compared to Baseline, Using Alternative Approaches to Represent PM$_{2.5}$ Mortality Risk Effects (95% Confidence Interval; Million of 2018$)

Year	No-threshold Model[b]			Limited to Above LML[c]			Effects Above NAAQS[d]		
3% Discount Rate									
2021	$160 ($15 to $430)	to	$370 ($33 to $1000)	$140 ($14 to $380)	to	$300 ($27 to $850)	$14 ($2 to $36)	to	$38 ($3.9 to $110)
2023	$77 (-$20 to $230)	to	$160 (-$80 to $540)	$88 (-$19 to $260)	to	$24 (-$92 to $160)	-$6 (-$27 to $8.7)	to	-$28 (-$97 to $8.3)
2025	$21 (-$29 to $86)	to	$33 (-$110 to $200)	$34 (-$28 to $120)	to	-$49 (-$150 to $4.4)	-$9.2 (-$32 to $4.9)	to	-$35 (-$110 to $5.6)
2030	-$41 (-$120 to $0.33)	to	-$91 (-$270 to $2.5)	-$0.4 (-$6.2 to $5.5)	to	-$110 (-$310 to $4.5)	$0.43 (-$3.9 to $5.6)	to	$3.2 (-$3.7 to $14)
2035	-$120 (-$330 to -$4.4)	to	-$260 (-$760 to -$7.9)	-$96 (-$270 to -$2)	to	-$220 (-$630 to -$3)	-$1.5 (-$9.9 to $6.7)	to	$1.6 (-$9.7 to $16)
2040	$320 ($31 to $870)	to	$740 ($66 to $2100)	$300 ($29 to $830)	to	$490 ($44 to $1400)	$34 ($4.3 to $91)	to	$93 ($9 to $270)
2045	-$81 (-$250 to $19)	to	-$170 (-$570 to $64)	-$60 (-$190 to $22)	to	-$150 (-$500 to $69)	$6.8 (-$7.1 to $28)	to	$25 (-$5.6 to $84)
7% Discount Rate									
2021	$140 ($14 to $390)	to	$330 ($30 to $950)	$130 ($13 to $350)	to	$270 ($25 to $770)	$14 ($1.9 to $36)	to	$38 ($3.9 to $110)
2023	$69 (-$20 to $210)	to	$140 (-$82 to $490)	$78 (-$19 to $240)	to	$19 (-$93 to $140)	-$6.1 (-$27 to $8.6)	to	-$28 (-$97 to $8)
2025	$18 (-$30 to $78)	to	$26 (-$110 to $180)	$29 (-$29 to $110)	to	-$48 (-$150 to $4)	-$9.3 (-$32 to $4.6)	to	-$35 (-$110 to $5.1)
2030	-$37 (-$100 to $0.72)	to	-$82 (-$240 to $3.3)	-$0.35 (-$5.9 to $5.4)	to	-$95 (-$280 to $5.1)	$0.4 (-$3.9 to $5.4)	to	$3.2 (-$3.7 to $14)
2035	-$110 (-$290 to -$3.3)	to	-$240 (-$680 to -$5.6)	-$86 (-$240 to -$1.1)	to	-$190 (-$570 to -$1.1)	-$1.4 (-$9.8 to $6.7)	to	$1.6 (-$9.6 to $16)
2040	$290 ($28 to $790)	to	$670 ($60 to $1900)	$280 ($27 to $750)	to	$450 ($41 to $1300)	$33 ($4.3 to $90)	to	$92 ($8.9 to $270)
2045	-$73 (-$220 to $20)	to	-$150 (-$510 to $66)	-$53 (-$170 to $22)	to	-$130 (-$450 to $70)	$6.8 (-$7 to $28)	to	$25 (-$5.6 to $84)

a. Values rounded to two significant figures. Negative values indicate forgone benefits. Lower bound of confidence interval represents the 95% confidence estimate that is lower in value than the point estimate, while upper bound represents the estimate that is higher in value than the point estimate.

b. PM$_{2.5}$ effects quantified using a no-threshold model. Low end of range reflects dollar value of effects quantified using concentration-response parameter from Krewski et al. (2009) and Smith et al. (2008) studies; upper end quantified using parameters from Lepeule et al. (2012) and Jerrett et al. (2009). Full range of ozone effects is included.

Table 8-12: Estimated Economic Value of Avoided PM2.5 and Ozone-Attributable Deaths and Illnesses for the Final Rule, Compared to Baseline, Using Alternative Approaches to Represent $PM_{2.5}$ Mortality Risk Effects (95% Confidence Interval; Million of 2018$)

Year	No-threshold Model[b]	Limited to Above LML[c]	Effects Above NAAQS[d]

c. $PM_{2.5}$ effects quantified at or above the Lowest Measured Level of each long-term epidemiological study. Low end of range reflects dollar value of effects quantified down to LML of Krewski et al. (2009) study (5.8 µg/m3); high end of range reflects dollar value of effects quantified down to LML of Lepeule et al. (2012) study (8 µg/m3). Full range of ozone effects is still included.

d. PM effects only quantified at or above the annual mean of 12 $\mu g/m^3$ to provide insight regarding the fraction of benefits occurring above the NAAQS. Range reflects effects quantified using concentration-response parameters from Smith et al. (2008) study at the low end and Jerrett et al. (2009) at the high end. Full range of ozone effects is still included.

Source: U.S. EPA Analysis, 2020

Table 8-13: Estimated Percent of Avoided $PM_{2.5}$-related Premature Deaths Above and Below $PM_{2.5}$ Concentration Cut Points for the Final Rule, Compared to Baseline

Year	Epidemiological Study	Total Mortality	Avoided $PM_{2.5}$-related Premature Deaths Reported by Air Quality Cutpoint[a]					
			Above NAAQS		Below NAAQS and Above LML[c]		Below LML[c]	
2021	Krewski et al. (2009)	15	<1	(<1%)	13	(86%)	2	(12%)
	Lepeule et al. (2012)	34	<1	(<1%)	26	(78%)	7	(21%)
2023	Krewski et al. (2009)	8	<1	(<1%)	9	[b](118%)	-1	(-13%)
	Lepeule et al. (2012)	19	<1	(<1%)	5	(28%)	14	(72%)
2025	Krewski et al. (2009)	3	<1	(3%)	4	[b](143%)	-1	(-43%)
	Lepeule et al. (2012)	7	<1	(2%)	-1	(-20%)	8	[b](117%)
2030	Krewski et al. (2009)	-4	<1	(-1%)	>-1	(2%)	-4	(100%)
	Lepeule et al. (2012)	-9	<1	(-1%)	-11	[b](119%)	1	(-16%)
2035	Krewski et al. (2009)	-11	<1	(<1%)	-9	(82%)	-2	(19%)
	Lepeule et al. (2012)	-25	<1	(<1%)	-20	(83%)	-4	(18%)
2040	Krewski et al. (2009)	27	<1	(<1%)	25	(94%)	1	(5%)
	Lepeule et al. (2012)	61	<1	(<1%)	37	(61%)	23	(38%)
2045	Krewski et al. (2009)	-8	<1	(<1%)	-6	(75%)	-2	(24%)
	Lepeule et al. (2012)	-18	<1	(<1%)	-16	(88%)	-2	(12%)

a. Values rounded to the nearest integer.

b. Avoided premature deaths below a threshold may be negative, while avoided premature deaths above a different threshold may be positive. This can result in the percent of avoided $PM_{2.5}$-related premature deaths above a certain threshold exceeding 100%.

c. The LML of the Krewski et al. (2009) study is 5.8 $\mu g/m^3$ and 8 $\mu g/m^3$ for Lepeule et al. (2012) study.

Source: U.S. EPA Analysis, 2020

8.4 Annualized Air Quality-Related Benefits of Regulatory Options

EPA calculated the present value of estimated air quality-related benefits and annualized these values using 3 percent and 7 percent discount rates to provide a measure that is comparable to the way other benefit categories and social costs are reported.

Sections 8.2 and 8.3 provide benefit estimates for Option A, the final rule, based on the changes in the electricity generation profile projected in IPM. As discussed in Section 8.3.1.1, the analysis of human health benefits does not account for other changes in pollutant emissions associated with power requirements to operate wastewater treatment systems or transport CCR or other solid waste. EPA examined the effects of adjusting the estimated benefits in proportion to the average ratio between total air emissions of NO_X and SO_2 (Table 8-5) and EGU emissions associated with changes in the electricity generation profile (Table 8-3) for the final rule and found that such an adjustment would have a negligible effect on human health benefit estimates given interannual variability and discounting effects. Therefore, EPA is presenting unadjusted values for the final rule below.

Because EPA did not run IPM for Options B and C, EPA did not analyze domestic climate and human health benefits for Options B and C using the same modeling approach used for Option A. To provide insight into the potential air quality-related benefits across regulatory options, EPA estimated benefits for Options B and C by scaling Option A benefits in proportion to the social costs of the respective options (see Section 12.2). This scaling factor is appropriate since changes in the profile of electricity generation account for the majority of changes in air emissions (see Table 8-3 and Table 8-5) and this generation profile is affected most directly by the incremental technology implementation costs. Specifically, EPA calculated the ratio of the benefits to total social costs for Option A, then multiplied total social costs for Options B and C by this ratio. Table 8-14 summarizes the annualized air quality-related benefits of the regulatory options. Table 8-15 and Table 8-16 present results using alternative cut-points for $PM_{2.5}$ related mortality risk benefits.

Table 8-14: Total Annualized Air Quality-Related Benefits of Regulatory Options, Compared to the Baseline, 2021-2047 (Millions of 2018$)

Regulatory Option	3% Discount Rate[a]					7% Discount Rate[a]				
	Climate Change	Human Health		Total Benefits		Climate Change	Human Health		Total Benefits	
		Krewski / Smith	Lepeule / Jerrett	Lower Bound[b]	Upper Bound[c]		Krewski / Smith	Lepeule / Jerrett	Lower Bound[b]	Upper Bound[c]
Option A (Final Rule)	-$14	$28	$65	$14	$51	-$2.3	$25	$56	$23	$54
Option B[d]	-$11	$23	$52	$11	$41	-$1.9	$21	$46	$19	$44
Option C[d]	$2.3	-$4.7	-$11	-$2.4	-$8.5	-$0.27	$3.0	$6.6	$2.7	$6.4

a. Values rounded to two significant figures. Negative values indicate forgone benefits.

b. Lower bound based on human health benefit point estimates using Krewski et al. (2009) for $PM_{2.5}$ and Smith et al (2009) for ozone.

c. Upper bound based on human health benefit point estimates using Lepeule et al. (2012) for $PM_{2.5}$ and Jerrett et al. (2009) for ozone.

d. EPA estimated air quality-related benefits for Options B and C by multiplying the total social costs for each option (see Section 12.2) by the ratio of [air quality-related benefits / total social costs] for Option A.

Source: U.S. EPA Analysis, 2020

Table 8-15: Total Annualized Air Quality-Related Benefits of Regulatory Options, Compared to the Baseline, 2021-2047, Showing Only $PM_{2.5}$ Related Premature Mortality Risk Benefits above the Lowest Measured Level of Each Long-Term $PM_{2.5}$ Mortality Study (Millions of 2018$)

Regulatory Option	3% Discount Rate[a]					7% Discount Rate[a]				
	Climate Change	Human Health		Total Benefits		Climate Change	Human Health		Total Benefits	
		Krewski / Smith	Lepeule / Jerrett	Lower Bound[b]	Upper Bound[c]		Krewski / Smith	Lepeule / Jerrett	Lower Bound[b]	Upper Bound[c]
Option A (Final Rule)	-$14	$43	$4.4	-$9.4	$29	-$2.3	$38	$1.5	-$0.80	$36
Option B[d]	-$11	$35	$3.6	-$7.7	$23	-$1.9	$31	$1.2	-$0.66	$29
Option C[d]	$2.3	-$7.2	-$0.74	$1.6	-$4.9	-$0.27	$4.5	$0.18	-$0.094	$4.2

a. Values rounded to two significant figures. Negative values indicate forgone benefits.

b. Lower bound based on human health benefit point estimates using Lepeule et al. (2012) for $PM_{2.5}$ and Jerrett et al. (2009) for ozone.

c. Upper bound based on human health benefit point estimates using Krewski et al. (2009) for $PM_{2.5}$ and Smith et al (2009) for ozone.

d. EPA estimated air quality-related benefits for Options B and C by multiplying the total social costs for each option (see Section 12.2) by the ratio of [air quality-related benefits / total social costs] for Option A.

Source: U.S. EPA Analysis, 2020

Table 8-16: Total Annualized Air Quality-Related Benefits of Regulatory Options Compared to the Baseline, 2021-2047, showing only $PM_{2.5}$ Related Premature Mortality Risk Benefits above $PM_{2.5}$ National Ambient Air Quality Standard (Millions of 2018$)

Regulatory Option	3% Discount Rate[a]					7% Discount Rate[a]				
	Climate Change	Human Health		Total Benefits		Climate Change	Human Health		Total Benefits	
		Krewski / Smith	Lepeule / Jerrett	Lower Bound[b]	Upper Bound[c]		Krewski / Smith	Lepeule / Jerrett	Lower Bound[b]	Upper Bound[c]
Option A (Final Rule)	-$14	$4.1	$11	-$9.7	-$3.3	-$2.3	$1.9	$3.4	-$0.40	$1.1
Option B[d]	-$11	$3.3	$8.5	-$7.9	-$2.7	-$1.9	$1.6	$2.8	-$0.33	$0.91
Option C[d]	$2.3	-$0.69	-$1.8	$1.6	$0.56	-$0.27	$0.23	$0.40	-$0.047	$0.13

a. Values rounded to two significant figures. Negative values indicate forgone benefits.

b. Lower bound based on human health benefit point estimates using Krewski et al. (2009) for $PM_{2.5}$ and Smith et al (2009) for ozone.

c. Upper bound based on human health benefit point estimates using Lepeule et al. (2012) for $PM_{2.5}$ and Jerrett et al. (2009) for ozone.

d. EPA estimated air quality-related benefits for Options B and C by multiplying the total social costs for each option (see Section 12.2) by the ratio of [air quality-related benefits / total social costs] for Option A.

Source: U.S. EPA Analysis, 2020

8.5 Limitations and Uncertainties

Table 8-17 summarizes the limitations and uncertainties associated with the analysis of the air quality-related benefits. The effect on benefits estimates indicated in the second column of the table refers to the magnitude of the benefits rather than the direction (*i.e.*, a source of uncertainty that tends to underestimate benefits indicates expectation for either larger forgone benefits or larger realized benefits). The analysis also incorporates uncertainties associated with IPM modeling, which are discussed in Chapter 5 in the *RIA* (U.S. EPA, 2020d). See *Appendix I* and *Appendix J* for additional discussions of the uncertainty associated with the climate change benefit estimates and air quality modeling methodology, respectively.

Table 8-17: Limitations and Uncertainties in Analysis of Air Quality-Related Benefits

Uncertainty/Limitation	Effect on Benefits Estimate	Notes
EPA extrapolated Option A benefits to Options B and C.	Uncertain	EPA ran IPM only for Option A and used the results to extrapolate benefits of Options B and C, based on the ratios of annualized benefits and annualized social costs. Air emissions and air quality changes are unlikely to follow differences in social costs in a linear fashion, however, given how marginal changes in operating costs for individual units may affect dispatch of EGUs within the broader regional and national electricity markets. Projected benefits for Options B and C are therefore uncertain, with the uncertainty expected to be greatest for Option C.
Domestic SC-CO_2 estimates do not capture the full range of impacts from climate change.	Underestimate	Current integrated assessment models (IAMs) used in developing the SC-CO_2 do not model all relevant regional interactions – *i.e.*, how climate change impacts in other regions of the world could affect the United States, through pathways such as global migration, economic destabilization, and political destabilization.
The modeled air quality surfaces used in the analysis of human health benefits only reflect changes in emissions associated with changes in the electricity generation profile.	Uncertain	EPA developed the spatial fields based on IPM projected emissions changes for Option A. These projections do not include additional changes in NO_X and SO_2 emissions associated with power requirements to operate wastewater treatment systems or transport CCR and other solid waste. While these emissions changes could affect human health benefit estimates, such effects are expected to be minimal given that these emissions generally represent less than 1 percent of total NO_X and SO_2 emissions changes.
The health impact function for fine particles is log-linear without a threshold.	Uncertain	The estimates include health benefits from reducing fine particles in areas with different concentrations of $PM_{2.5}$, including both areas that do not meet the fine particle standard and those areas that are in attainment and reflect the full distribution of $PM_{2.5}$ air quality simulated above.
All fine particles, regardless of their chemical composition, are equally potent in causing premature mortality.	Uncertain	The PM ISA concluded that "many constituents of $PM_{2.5}$ can be linked with multiple health effects, and the evidence is not yet sufficient to allow differentiation of those constituents or sources that are more closely related to specific outcomes" (U.S. EPA, 2009a). The 2019 PM ISA reaffirmed this conclusion (U.S. EPA, 2019e).

Table 8-17: Limitations and Uncertainties in Analysis of Air Quality-Related Benefits

Uncertainty/Limitation	Effect on Benefits Estimate	Notes
There is a "cessation" lag between the change in PM exposures and the total realization of changes in mortality effects.	Uncertain	The approach distributes the incidences of premature mortality related to $PM_{2.5}$ exposures over the 20 years following exposure based on the advice of the EPA Science Advisory Board Health Effect Subcommittee (SAB-HES) (U.S. EPA, 2004). This distribution affects the valuation of mortality benefits at different discount rates. The actual distribution of effects over time is uncertain.
Climate changes may affect ambient concentrations of pollutants.	Uncertain	Estimated health benefits do not account for the influence of future changes in the climate on ambient concentrations of pollutants (U.S. Global Change Research Program, 2016). For example, recent research suggests that future changes to climate may create conditions more conducive to forming ozone; the influence of changes in the climate on $PM_{2.5}$ concentrations are less clear (Fann *et al.*, 2015). The estimated health benefits also do not consider the potential for climate-induced changes in temperature to modify the relationship between ozone and the risk of premature death (Jhun *et al.*, 2014; Ren, Williams, Mengersen, *et al.*, 2008; Ren, Williams, Morawska, *et al.*, 2008).
EPA did not analyze all benefits of changes in NO_X, SO_2, and other pollutants emitted by EGUs.	Underestimate	The analysis focused on adverse health effects related to $PM_{2.5}$ and ozone levels. There are additional direct benefits from changes in levels of NO_X, SO_2 and other air pollutants emitted by EGUs (*e.g.*, Hg, HCl). As described in U.S. EPA (2019f), these include health benefits from changes in ambient NO_2 and SO_2 exposure, health benefits from changes in mercury deposition, ecosystem benefits associated with changes in emissions of NO_X, SO_2, PM, and mercury, and visibility impairment.

9 Changes in Water Withdrawals

Steam electric power plants use water for ash transport and for operating wet FGD scrubbers. The regulatory options are estimated to change water withdrawal from surface waterbodies and aquifers by affecting sluicing operations or incentives to recycle water within the plants.

Table 9-1 shows estimated changes in water withdrawals for each regulatory option.

Table 9-1: Industry-level Total Changes in Water Withdrawals under the Regulatory Options, Compared to Baseline (Both Surface Water and Aquifers)

Regulatory Option	Change in Water Withdrawals (Million Gallons per Day)[a]
Option D[a]	*3.37*
Option A[c] (Final Rule)	3.94
Option B[c]	4.49
Option C[c]	-9.93

a. Negative values represent a decrease in water withdrawals compared to the baseline, whereas positive values represent an increase in water use.

b. Option D corresponds to the proposed Option 1. EPA did not reanalyze this option for the final rule. All results shown for Option D are based on the 2019 analysis, as detailed in the 2019 BCA (U.S. EPA, 2019a). As such, the values do not reflect changes in the baseline, plant universe, and other analytical inputs for the analysis of Options A, B, and C.

c. Groundwater withdrawals are included in the total and are estimated to increase by 12,300 gallons per day under regulatory options A, B, and C.

Source: U.S. EPA Analysis, 2020

The sections below discuss the benefits resulting specifically from estimated changes in groundwater withdrawals. Benefits associated with surface water withdrawals are discussed qualitatively in Chapter 2.

The analysis shows very small effects from the final rule on water withdrawals compared to baseline (see U.S. EPA, 2015a).

9.1 Methods

The analysis follows the same general methodology EPA used in the analysis of the 2015 rule and the 2019 proposal (U.S. EPA, 2015a; 2019a). Changes in water withdrawal from groundwater sources by steam electric power plants may affect availability of groundwater for local municipalities that rely on aquifers for drinking water supplies. These municipalities may incur incremental costs for supplementing drinking water supplies through alternative means, such as bulk water purchases as water withdrawals by steam electric power plants change. EPA estimated the monetary value of changes in groundwater withdrawals based on costs of purchasing drinking water during periods of shortages in groundwater supply.

9.2 Results

EPA estimated that regulatory options A, B, and C would result in one plant increasing the volume of groundwater withdrawn. See details in the *Supplemental TDD* (U.S. EPA, 2020g).

The estimated increase in groundwater withdrawals is 12,300 gallons per day (4.5 million gallons per year) under Options A, B, and C. EPA estimated that demand for additional water supply exists in the affected areas due to potential drought (Tetra Tech, 2010). To estimate the value of reduced groundwater supply, EPA used state-specific prices of bulk drinking water supplies, given that municipalities may need to purchase supplementary supplies in response to any change in groundwater availability arising from additional withdrawals by steam electric plants. This analysis provides screening-level indication of the potential forgone benefits.

To estimate the monetary value of the changes in groundwater withdrawals, EPA multiplied the increase in groundwater withdrawal (in gallons per year) by the estimated retail price of drinking water ($947.73 per acre-foot for the affected location; Lincoln Public Works and Utilities, 2018) times a conversion factor of 325,851 to convert acre foot to gallons.[76]

Table 9-2 shows estimated annual forgone benefits from increased groundwater withdrawals under the regulatory options. The annual forgone benefits are $0.01 million using both 3 percent and 7 percent discount rates under regulatory options A, B, and C.

Table 9-2: Estimated Annualized Benefits from Changes in Groundwater Withdrawals under the Regulatory Options, Compared to Baseline (Millions of 2018$)

Regulatory Option	Change in Groundwater Withdrawals (Million Gallons per Year)[a]	3% Discount Rate	7% Discount Rate
Option D[b]	*0.0*	*$0.00*	*$0.00*
Option A (Final Rule)	4.5	-$0.01	-$0.01
Option B	4.5	-$0.01	-$0.01
Option C	4.5	-$0.01	-$0.01

a. Reflects changes after implementation of technologies to meet the regulatory option.

b. Option D corresponds to the proposed Option 1. EPA did not reanalyze this option for the final rule. All results shown for Option D are based on the 2019 analysis, as detailed in the 2019 BCA (U.S. EPA, 2019a). As such, the values do not reflect changes in the baseline, plant universe, and other analytical inputs for the analysis of Options A, B, and C.

Source: U.S. EPA Analysis, 2020

9.3 Limitations and Uncertainties

Table 9-3 summarizes the limitations and uncertainties in the analysis of benefits associated with changes in groundwater withdrawals. Note that the effect on benefits estimates indicated in the second column of the table refers to the magnitude of the benefits rather than the direction (*i.e.*, a source of uncertainty that tends to underestimate benefits indicates expectation for larger forgone benefits or for larger realized benefits).

Table 9-3: Limitations and Uncertainties in Analysis of Changes in Groundwater Withdrawals

Uncertainty/Limitation	Effect on Benefits Estimate	Notes
EPA estimated that municipalities would need to replace lost groundwater supplies with bulk drinking water purchases.	Uncertain	Municipalities may not need to replace groundwater withdrawn by steam electric power plants (in which case the benefits of the final rule may be overstated), or they may choose to replace the groundwater through other means.

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[76] Water prices are uncertain. Average prices for irrigation water within the same geographic area range from approximately $50 to $300 per acre-foot, with some water trades reaching $1,800 per acre-foot. Using these alternative prices would not have a large impact on EPA's overall benefit estimates, however, given the small change in withdrawals under the regulatory options.

Table 9-3: Limitations and Uncertainties in Analysis of Changes in Groundwater Withdrawals

Uncertainty/Limitation	Effect on Benefits Estimate	Notes
EPA estimated a direct relationship between groundwater withdrawals in water-stressed states and groundwater shortages, *i.e.*, that reducing demand for limited groundwater supplies would result in avoided costs for purchased water.	Overestimate	EPA estimated that demand for additional water supply exists in the affected areas due to potential drought. However, the extent of this demand is uncertain.
EPA estimated cost of bulk water purchases based on state-wide averages.	Uncertain	Costs of water may vary within a state and using the average value may result in under- or overstating of the cost for any given location. This uncertainty is more significant in cases where there are few affected locations, as is the case for this analysis which shows only one plant with changes in groundwater withdrawals.
Data on the characteristics of affected aquifers are not available.	Uncertain	If the affected aquifers are used for private wells only, the estimated benefits of improved groundwater recharge could be under- or overstated, depending on households' WTP for protecting groundwater quantity.

10 Estimated Changes in Dredging Costs

As summarized in Table 3-3, the regulatory options could result in small changes in suspended solid discharges by steam electric power plants, which could have an impact on the rate of sediment deposition in affected reaches, including navigable waterways and reservoirs that require dredging for maintenance.

Navigable waterways, including rivers, lakes, bays, shipping channels and harbors, are an integral part of the United States' transportation network. They are prone to reduced functionality due to sediment build-up, which can reduce the navigable depth and width of the waterway (Clark *et al.*, 1985; M. Ribaudo, 2011). In many cases, costly periodic dredging is necessary to keep them passable. The regulatory options could increase or reduce costs for government and private entities responsible for maintenance of navigable waterways by changing the need for dredging.

Reservoirs serve many functions, including water storage for drinking, irrigation, and hydropower uses, flood control, and recreation. Streams and rivers carry sediment into reservoirs, where it can settle and build up at a recorded average rate of 1.2 billion kilograms per reservoir every year (USGS, 2009). Sedimentation reduces reservoir capacity (Graf *et al.*, 2010) and the useful life of reservoirs unless measures such as dredging are taken to reclaim capacity (Clark *et al.*, 1985; Hargrove *et al.*, 2010; Miranda, 2017).

EPA estimated that the final rule, Option A, will have a small effect on historical average dredging costs when compared to those estimated in 2015 for the 2015 rule (see U.S. EPA, 2015a).

10.1 Methods

In this analysis, EPA followed the same general methodology for estimating changes in costs associated with changes in sediment depositions in navigational waterways and reservoirs that EPA used in the 2015 rule and 2019 proposal (U.S. EPA, 2015a [see Appendix K]; 2019a).[77] The methodology utilizes information on historic dredging locations, frequency of dredging, the amount of sediment removed, and dredging costs in conjunction with the estimated changes in net sediment deposition (sedimentation minus erosion) in dredged waterways and reservoirs under the regulatory options. Benefits are equal to avoided costs, calculated as the difference from historical averages in total annualized dredging costs due to changes between the baseline and the regulatory options. Negative values represent cost increases (*i.e.*, forgone benefits to society).

10.1.1 Estimated Changes in Navigational Dredging Costs

EPA identified 250 unique dredging jobs and 393 dredging occurrences[78] within the affected reaches. This corresponds to approximately 13 percent of the dredging occurrences with coordinates reported in the Dredging Information System (U.S. Army Corps of Engineers, 2013). The recurrence interval for dredging jobs ranged from one to 15 years across affected reaches and averaged 13.3 years. Dredging costs vary considerably across geographic locations and dredging jobs from approximately $0.11 per cubic yard at

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[77] For the final rule analysis, EPA made one change to the methodology used to estimate net sediment deposition at any given location in the reach network by using the *TOTAL_YIELD* output variable from the SPARROW models instead of *INC_TOTAL_YIELD*.

[78] Dredging jobs refer to unique sites/locations defined by the U.S. Army Corps of Engineers where dredging was conducted, whereas dredging occurrences are unique instances when dredging was conducted and may include successive dredging at the same location.

Sardine Point in Louisiana to $80.87 per cubic yard at Service Point in Illinois. The median unit cost of dredging for the entire conterminous United States is $6.44 per cubic yard.

Table 10-1 presents low, mean, and high estimates of dredged sediment volume and dredging costs during the period of 2021 through 2047 in navigational waterways that may be affected by steam electric plant discharges, based on historical averages. EPA generated low, medium, and high estimates for navigational dredging by varying the projected future dredging occurrence, including dredging frequency and job start as well as cost of dredging for locations that did not report location specific costs (see U.S. EPA, 2015a, Appendix K for details). Estimated total navigational dredging costs based on historical averages range from $66.1 million to $155.0 million per year, using a 3 percent discount rate, and from $57.2 million to $162.1 million using a 7 percent discount rate.

Table 10-1: Estimated Annualized Navigational Dredging Costs at Affected Reaches Based on Historical Averages (Millions of 2018$)

Total Sediment Dredged (Millions Cubic Yards)			Costs at 3% Discount Rate (Millions of 2018$ per Year)			Costs at 7% Discount Rate (Millions of 2018$ per Year)		
Low	Mean	High	Low	Mean	High	Low	Mean	High
897.6	907.9	1,365.0	$66.1	$69.2	$155.0	$57.2	$59.6	$162.1

Source: U.S. EPA analysis, 2020.

The difference between the estimated dredging costs using historical averages and costs resulting from the incremental sediment deposition under a regulatory option as compared to baseline represents the avoided costs (or forgone benefits) of the regulatory option. Table 10-2 presents estimated changes in navigational dredging costs for the regulatory options.

Table 10-2: Estimated Annualized Changes in Navigational Dredging Costs under the Regulatory Options, Compared to Baseline

Regulatory Option	Total Reduction in Sediment Dredged (Thousands Cubic Yards)			3% Discount Rate (Thousands of 2018$ per Year)[a]			7% Discount Rate (Thousands of 2018$ per Year)[a]		
	Low	Mean	High	Low	Mean	High	Low	Mean	High
Option D[b]	*-91.4*	*-92.1*	*-100.4*	*-$37.5*	*-$38.0*	*-$47.2*	*-$33.1*	*-$33.4*	*-$45.2*
Option A (Final Rule)	-0.9	-0.9	-1.3	-$0.1	-$0.1	-$0.2	-$0.1	-$0.1	-$0.2
Option B	-0.9	-0.9	-1.2	-$0.1	-$0.1	-$0.1	-$0.1	-$0.1	-$0.1
Option C	14.8	14.8	15.1	$5.5	$5.5	$5.8	$4.8	$4.8	$5.3

a. Positive values represent cost savings; negative values represent cost increases.

b. Option D corresponds to the proposed Option 1. EPA did not reanalyze this option for the final rule. All results shown for Option D are based on the 2019 analysis, as detailed in the 2019 BCA (U.S. EPA, 2019a). As such, the values do not reflect changes in the baseline, plant universe, and other analytical inputs for the analysis of Options A, B, and C (including changes in the sediment models and basis for estimating sediment depositions).

Source: U.S. EPA analysis, 2020.

10.1.2 Estimated Changes in Reservoir Dredging Costs

EPA identified 2,747 reservoirs within the affected reaches with changes in sediment loads under at least one of the regulatory options, corresponding to approximately one percent of the reservoirs represented in the SPARROW models (Ator, 2019; Hoos & Roland Ii, 2019; Robertson & Saad, 2019; Wise, 2019; Wise *et al.*, 2019). EPA used regional estimates of median dredging costs to calculate changes in reservoir dredging costs under the regulatory options. The median cost per cubic yard ranges from $2.72 in EPA Region 2 to $31.38 in EPA Region 5, with a national median value of $6.44. Table 10-3 presents low, mean, and high estimates of the projected volume of sediment to be dredged during the period of 2021 through 2047 from these reservoirs and estimated annualized dredging costs, based on historical averages. Estimated reservoir dredging costs based on historical averages range between $144.2 million and $195.7 million using a 3 percent discount rate and $120.7 million and $179.9 million using a 7 percent discount rate.

Table 10-3: Estimated Annualized Reservoir Dredging Volume and Costs based on Historical Averages

Total Sediment Dredged (Millions Cubic Yards)			Costs at 3% Discount Rate (Millions of 2018$ per Year)			Costs at 7% Discount Rate (Millions of 2018$ per Year)		
Low	**Mean**	**High**	**Low**	**Mean**	**High**	**Low**	**Mean**	**High**
708.3	850.0	920.8	$144.2	$174.6	$195.7	$120.7	$151.5	$179.9

Source: U.S. EPA analysis, 2020.

The difference between the estimated dredging costs using historical averages and costs resulting from the incremental sediment deposition under a regulatory option as compared to baseline represents the avoided costs for that regulatory option. Table 10-4 presents estimated cost changes for reservoir dredging under the regulatory options, including low, mean, and high estimates.

Table 10-4: Estimated Total Annualized Changes in Reservoir Dredging Volume and Costs under the Regulatory Options, Compared to Baseline

	Total Reduction in Sediment Dredged (Thousands Cubic Yards)			Costs at 3% Discount Rate[a] (Thousands of 2018$ per Year)			Costs at 7% Discount Rate[a] (Thousands of 2018$ per Year)		
Regulatory Option	**Low**	**Mean**	**High**	**Low**	**Mean**	**High**	**Low**	**Mean**	**High**
Option D[b]	*-141.0*	*-169.2*	*-183.3*	*-$29.7*	*-$35.9*	*-$40.3*	*-$24.9*	*-$31.2*	*-$37.0*
Option A (Final Rule)	-2.0	-2.7	-3.0	-$0.4	-$0.5	-$0.6	-$0.3	-$0.5	-$0.6
Option B	-1.3	-1.6	-1.8	-$0.3	-$0.4	-$0.4	-$0.2	-$0.3	-$0.4
Option C	-0.3	-1.1	-1.4	-$0.1	-$0.3	-$0.4	-$0.1	-$0.3	-$0.4

a. Positive values represent cost savings; negative values represent cost increases.

b. Option D corresponds to the proposed Option 1. EPA did not reanalyze this option for the final rule. All results shown for Option D are based on the 2019 analysis, as detailed in the 2019 BCA (U.S. EPA, 2019a). As such, the values do not reflect changes in the baseline, plant universe, and other analytical inputs for the analysis of Options A, B, and C (including changes in the sediment models and basis for estimating sediment depositions).

Source: U.S. EPA analysis, 2020.

10.2 Limitation and Uncertainty

Table 10-5 summarizes key uncertainties and limitations in the analysis of sediment dredging benefits. A more detailed description is provided in Appendix K of the 2015 *BCA* (U.S. EPA, 2015a). Note that the effect on benefits estimates indicated in the second column of the table refers to the magnitude of the benefits rather than the direction (*i.e.*, a source of uncertainty that tends to underestimate benefits indicates expectation for larger forgone benefits or for larger realized benefits). Uncertainties and limitations associated with SPARROW model estimates of sediment deposition are discussed in the respective regional model reports (Ator, 2019; Hoos & Roland Ii, 2019; Robertson & Saad, 2019; Wise, 2019; Wise *et al.*, 2019).

Table 10-5: Limitations and Uncertainties in Analysis of Changes in Dredging Costs

Uncertainty/Limitation	Effect on Benefits Estimate	Notes
The analysis scales dredging volumes and costs in proportion to the percent change in sediment deposition in navigational waterways and reservoirs.	Uncertain	EPA estimated a linear relationship between changes in sediment deposition and dredging volumes and costs which may not capture non-linear dynamics in the relationships between sediment deposition and dredging volumes and between dredging volumes and costs.
The analysis of navigational waterways includes only jobs reported for 1998 through 2012 (U.S. Army Corps of Engineers, 2013).	Underestimate	Because some dredging jobs included in the U.S. Army Corps of Engineers Database lack latitude and longitude and the database does not use standardized job names, EPA was only able to map approximately 71 percent of all recorded dredging occurrences. This may lead to potential underestimation of historical costs and changes in dredging costs under the regulatory options.
The analysis of reservoir dredging is limited to reservoirs identified on the NHD reach network.	Underestimate	The omission of other reservoirs could understate the magnitude of estimated historical costs and changes in reservoir dredging benefits if there are additional reservoirs located downstream from steam electric power plants.

11 Summary of Estimated Total Monetized Benefits

Table 11-1 and Table 11-2, on the next two pages, summarize the total annualized monetized benefits using 3 percent and 7 percent discount rates, respectively.

The monetized benefits do not account for all effects of the regulatory options, including changes in certain cancer and non-cancer health risk (*e.g.*, effects of halogenated disinfection byproducts in drinking water, effects of cadmium on kidney functions and bone density), impacts of pollutant load changes on T&E species habitat, etc. See Chapter 2 for a discussion of categories of benefits EPA did not monetize. Chapter 4 through Chapter 10 provide more detail on the estimation methodologies for each benefit category.

Table 11-1: Summary of Estimated Total Annualized Benefits of the Regulatory Options, Compared to Baseline, at 3 Percent (Millions of 2018$)

Benefit Category	*Option D*[a, b]	Option A[b] (Final Rule)	Option B[b]	Option C[b]
Human Health	***-$0.7***[c]	**-$0.3**	**-$0.3**	**-$0.1**
Changes in IQ losses in children from exposure to lead[d]	*<$0.0*	<$0.0	<$0.0	<$0.1
Changes in IQ losses in children from exposure to mercury	*-$0.3*	-$0.3	-$0.3	-$0.1
Ecological Conditions and Recreational Uses Changes	***-$12.5***	**-$15.3 to -$7.4**	**-$10.4 to -$5.5**	**-$9.9 to -$4.8**
Use and nonuse values for water quality changes[e]	*-$12.5*[i]	-$15.3 to -$7.4	-$10.4 to -$5.5	-$9.9 to -$4.8
Market and Productivity Effects[d]	***-$0.1***	**<$0.0**	**<$0.0**	**$0.0**
Changes in dredging costs[d]	*-$0.1*	<$0.0	<$0.0	<$0.0
Reduced water withdrawals[d]	*$0.0*	<$0.0	<$0.0	<$0.0
Air Quality-Related Effects	***$30***	**$14 to $51**	**$11 to $41**	**-$8.5 to -$2.4**
Climate change effects from changes in CO_2 emissions[f]	*-$30*	-$14	-$11	$2.3
Human health effects from changes in NO_X, SO_2, and $PM_{2.5}$ emissions[g]	*Not estimated*	$28 to $65	$23 to $52	-$11 to -$4.7
Total[g,h]	***-$43.3***	**-$1.7 to $43.3**	**$0.3 to $35.7**	**-$12.4 to -$13.4**

a. Option D corresponds to the proposed Option 1. EPA did not reanalyze this option for the final rule. All results shown for Option D are based on the 2019 analysis, as detailed in the 2019 BCA (U.S. EPA, 2019a). As such, the values do not reflect changes in the baseline, plant universe, and other analytical inputs for the analysis of Options A, B, and C.

b. Negative values represent forgone benefits and positive values represent realized benefits.

c. Total includes $0.4 million of benefits due to changes in bladder cancer risk from disinfection byproducts in drinking water as estimated for the 2019 proposed rule (U.S. EPA, 2019a).

d. "<$0.0" indicates that monetary values are greater than -$0.1 million but less than $0.0 million.

e. The range reflects the lower and upper bound willingness-to-pay estimates. See Chapter 6 for details.

f. Values for air-quality related effects are rounded to two significant figures. EPA estimated the air quality-related benefits for Option A. EPA extrapolated estimates of air quality-related benefits for Options B and C from the estimate for Option A that is based on IPM outputs. See Chapter 8 for details.

g. Values for air-quality related effects are rounded to two significant figures. The range reflects the lower and upper bound estimates of human health effects from changes in $PM_{2.5}$ and ozone levels. See Chapter 8 for details.

h. Values for individual benefit categories may not sum to the total due to independent rounding. Range is based on the low and high willingness to pay estimates and air quality-related effects.

i. Value reflects midpoint willingness-to-pay estimate. See 2019 BCA for details (U.S. EPA, 2019a).

Source: U.S. EPA Analysis, 2020

Table 11-2: Summary of Estimated Total Annualized Benefits of the Regulatory Options, Compared to Baseline, at 7 Percent (Millions of 2018$)

Benefit Category	*Option D[a, b]*	Option A[b] (Final Rule)	Option B[b]	Option C[b]
Human Health	***-$0.3[c]***	**-$0.1**	**-$0.1**	**-$0.1**
Changes in IQ losses in children from exposure to lead[d]	*<$0.0*	<$0.0	<$0.0	<$0.0
Changes in IQ losses in children from exposure to mercury	*-$0.1*	-$0.1	-$0.1	-$0.1
Ecological Conditions and Recreational Uses Changes	***-$10.9***	**-$16.4 to -$8.0**	**-$12.0 to -$5.8**	**-$13.9 to -$6.7**
Use and nonuse values for water quality changes[e]	*-$10.9[i]*	-$16.4 to -$8.0	-$12.0 to -$5.8	-$13.9 to -$6.7
Market and Productivity Effects[d]	***-$0.1***	**<$0.0**	**<$0.0**	**<$0.0**
Changes in dredging costs[d]	*-$0.1*	<$0.0	<$0.0	<$0.0
Reduced water withdrawals[d]	*$0.0*	<$0.0	<$0.0	<$0.0
Air Quality-Related Effects	***-$4.8***	**$23 to $54**	**$19 to $44**	**$2.7 to $6.4**
Climate change effects from changes in CO_2 emissions[f]	*-$4.8*	-$2.3	-$1.9	-$0.27
Human health effects from changes in NO_X, SO_2, and $PM_{2.5}$ emissions[g]	*Not estimated*	$25 to $56	$21 to $46	$3.0 to $6.6
Total[g,h]	***-$16. 0***	**$6.5 to $45.9**	**$6.9 to $38.1**	**-$11.3 to -$0.4**

a. Option D corresponds to the proposed Option 1. EPA did not reanalyze this option for the final rule. All results shown for Option D are based on the 2019 analysis, as detailed in the 2019 BCA (U.S. EPA, 2019a). As such, the values do not reflect changes in the baseline, plant universe, and other analytical inputs for the analysis of Options A, B, and C.

b. Negative values represent forgone benefits and positive values represent realized benefits.

c. Total includes $0.2 million of benefits due to changes in bladder cancer risk from disinfection byproducts in drinking water as estimated for the 2019 proposed rule (U.S. EPA, 2019a).

d. "<$0.0" indicates that monetary values are greater than -$0.1 million but less than $0.0 million.

e. The range reflects the lower and upper bound willingness-to-pay estimates. See Chapter 6 for details.

f. Values for air-quality related effects are rounded to two significant figures. EPA estimated the air quality-related benefits for Option A. EPA extrapolated estimates of air quality-related benefits for Options B and C from the estimate for Option A that is based on IPM outputs. See Chapter 8 for details.

g. Values for air-quality related effects are rounded to two significant figures. The range reflects the lower and upper bound estimates of human health effects from changes in $PM_{2.5}$ and ozone levels. See Chapter 8 for details.

h. Values for individual benefit categories may not sum to the total due to independent rounding. Range is based on the low and high willingness to pay estimates and air quality-related effects.

i. Value reflects midpoint willingness-to-pay estimate. See 2019 BCA for details (U.S. EPA, 2019a).

Source: U.S. EPA Analysis, 2020

12 Summary of Total Social Costs

This chapter discusses EPA's estimates of the costs to society under the regulatory options. Social costs include costs incurred by both private entities and the government (*e.g.*, in implementing the regulation). As described further in Chapter 10 of the *RIA* (U.S. EPA, 2020d), EPA did not evaluate incremental cost to state governments to evaluate and incorporate best professional judgment into NPDES permits. Consequently, the only category of costs used to calculate social costs are estimated technology implementation costs for steam electric power plants. As discussed below, these costs may be positive or negative, with the latter occurring when a regulatory option provides savings as compared to the baseline.

12.1 Overview of Costs Analysis Framework

The *RIA* (Chapter 3) presents EPA's development of costs for the estimated 914 steam electric power plants within the scope of the final rule (U.S. EPA, 2020d). These costs (pre-tax) are used as the basis of the social cost analysis. A subset of these plants incur non-zero costs under the baseline or the regulatory options.

As described in Chapter 1, EPA estimated that steam electric power plants, in the aggregate, will implement control technologies between 2021 and 2028, with the technology implementation schedule varying across wastestreams and regulatory options. For the analysis of social costs, EPA estimated a plant- and year-explicit schedule of technology implementation cost outlays over the period of 2021 through 2047.[79] This schedule accounts for retirements and repowerings by zeroing-out O&M costs to operate treatment systems in years following unit retirement or repowering. After creating a cost-incurrence schedule for each cost component, EPA summed the costs expected to be incurred in each year for each plant, then aggregated these costs to estimate the total costs for each year in the analysis period. Following the approach used for the 2015 rule analysis and 2019 proposal (U.S. EPA, 2015c, 2019g), after technology implementation costs were assigned to the year of occurrence, the Agency adjusted these costs for change between 2018 (the year when costs were estimated) and the year(s) of their incurrence as follows:

- All technology costs, except planning, were adjusted to their incurrence year(s) using the Construction Cost Index (CCI) from McGraw Hill Construction and the Gross Domestic Product (GDP) deflator index published by the U.S. Bureau of Economic Analysis (BEA);
- Planning costs were adjusted to their incurrence year(s) using the Employment Cost Index (ECI) Bureau of Labor Statistics (BLS) and GDP deflator.

The CCI and ECI adjustment factors were developed only through the year 2027; after these years, EPA assumed that the real change in prices is zero – that is, costs are expected to change in line with general inflation. EPA judges this to be a reasonable approach, given that capital expenditures will occur by 2028 and the uncertainty of long-term future price projections.

After developing the year-explicit schedule of total costs and adjusting them for predicted real change to the year of their incurrence, EPA calculated the present value of these cost outlays as of the rule promulgation year by discounting the cost in each year back to 2020, using both 3 percent and 7 percent discount rates. These discount rate values reflect guidance from the OMB regulatory analysis guidance document, Circular A-4 (OMB, 2003). EPA calculated the constant annual equivalent value (annualized value), again using the

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[79] The period of analysis extends through 2047 to capture a substantive portion of the life of the wastewater treatment technology at any steam electric power plant (20 or more years), and the last year of technology implementation (2028).

two values of the discount rate, 3 percent and 7 percent, over a 27-year social cost analysis period. EPA assumed no re-installation of wastewater treatment technology during the period covered by the social cost analysis.

To assess the economic costs of the regulatory options to society, EPA relied first on the estimated costs to steam electric power plants for the labor, equipment, material, and other economic resources needed to comply with the regulatory options (see U.S. EPA, 2020d for details). In this analysis, the market prices for labor, equipment, material, and other compliance resources represent the opportunity costs to society for use of those resources in regulatory compliance. EPA assumed in its social cost analysis that the regulatory options do not affect the aggregate quantity of electricity that will be sold to consumers and, thus, that the rule's social cost will include no changes in consumer and producer surplus *from changes in electricity sales* by the electricity industry in aggregate. Given the small impact of the regulatory options on electricity production cost for the total industry, this approach is reasonable for the social cost analysis (for more details on the impacts of the regulatory options on electricity production cost, see *RIA* Chapter 5). The social cost analysis considers costs on an as-incurred, year-by-year basis – that is, this analysis associates each cost component to the year(s) in which they are assumed to occur relative to the assumed rule promulgation and technology implementation years.[80]

Finally, as discussed in Chapter 10 of the *RIA* (U.S. EPA, 2020d; see Section 10.7: Paperwork Reduction Act of 1995), the regulatory options will not result in additional administrative costs for plants to implement, and state and federal NPDES permitting authorities to administer, the final rule. As a result, the social cost analysis focuses on the resource cost of compliance as the only direct cost incurred by society as a result of the regulatory options.

12.2 Key Findings for Regulatory Options

Table 12-1 presents annualized costs for the baseline and the analyzed regulatory options. The table also provides the incremental costs attributable to the regulatory options, calculated as the difference between each option and the baseline. As shown in the table, the regulatory options generally result in cost savings across the options and discount rates, with the exception of Option C which results in incremental costs at 3 percent discount rate. Thus, incremental costs range from -$127.1 million to $21.4 million at a 3 percent discount rate, and from -$153.4 million to -$18.2 million at a 7 percent discount rate.

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[80] The specific assumptions of when each cost component is incurred can be found in Chapter 3 of the *RIA*.

Table 12-1: Summary of Estimated Annualized Costs (Millions of 2018$)

Regulatory Option	Annualized Costs		Incremental Costs	
	3% Discount Rate	7% Discount Rate	3% Discount Rate	7% Discount Rate
Baseline	$309.6	$347.8		
Option D[a]	*$234.3*	*$263.0*	*-$130.6*	*-154.0*
Option A (Final Rule)	$182.5	$194.4	-$127.1	-$153.4
Option B	$206.4	$221.4	-$103.2	-$126.4
Option C	$331.1	$329.6	$21.4	-$18.2

a. Option D corresponds to the proposed Option 1. EPA did not reanalyze this option for the final rule. All results shown for Option D are based on the 2019 analysis, as detailed in the 2019 BCA (U.S. EPA, 2019a). As such, the values do not reflect changes in the baseline, plant universe, and other analytical inputs for the analysis of Options A, B, and C. Incremental costs for Option D are relative to the 2019 analysis baseline versus the baseline to which Options A, B, and C are compared. For these reasons, the values should not be used for direct comparisons to the final rule.

Source: U.S. EPA Analysis, 2020.

Table 12-2 provides additional detail on the social cost calculations. The table compiles, for the baseline and each regulatory option, the assumed time profiles of technology implementation costs incurred. The table also reports the estimated annualized values of costs at 3 percent and 7 percent discount rates (see bottom of the table). The maximum technology implementation outlays differ across the options but are incurred over the years 2021 through 2028, *i.e.*, during the estimated window (defined as Period 1 in Section 3.2.1) when steam electric power plants are expected to implement wastewater treatment technologies.

Table 12-2: Time Profile of Costs to Society (Millions of 2018$)

Year	Technology Implementation Costs					Incremental Costs			
	Baseline	*Option D[a]*	Option A (Final Rule)	Option B	Option C	*Option D[a]*	Option A (Final Rule)	Option B	Option C
2020	$0.0	*$0.0*	$0.0	$0.0	$0.0	*$0.0*	$0.0	$0.0	$0.0
2021	$998.2	*$673.5*	$518.4	$595.6	$223.1	*-$538.4*	-$479.8	-$402.5	-$775.1
2022	$540.0	*$487.0*	$193.1	$288.4	$229.0	*-$259.5*	-$346.9	-$251.5	-$310.9
2023	$1,551.8	*$1,231.1*	$246.6	$273.7	$118.4	*-$839.7*	-$1,305.2	-$1,278.1	-$1,433.4
2024	$201.8	*$135.2*	$305.2	$321.2	$393.0	*-$57.6*	$103.3	$119.4	$191.1
2025	$201.6	*$136.6*	$448.8	$494.5	$609.4	*-$58.4*	$247.2	$292.8	$407.7
2026	$196.5	*$131.4*	$117.2	$137.3	$1,036.2	*-$59.3*	-$79.4	-$59.2	$839.6
2027	$198.8	*$141.2*	$121.5	$139.1	$384.9	*-$60.3*	-$77.3	-$59.7	$186.1
2028	$186.7	*$129.4*	$238.7	$272.6	$707.4	*-$60.3*	$52.1	$85.9	$520.7
2029	$189.7	*$144.6*	$130.9	$143.9	$271.9	*-$60.3*	-$58.9	-$45.8	$82.2
2030	$187.6	*$141.6*	$129.8	$142.9	$271.5	*-$60.3*	-$57.8	-$44.6	$83.9
2031	$188.2	*$144.9*	$134.3	$147.4	$273.6	*-$60.3*	-$53.9	-$40.8	$85.4
2032	$188.4	*$146.8*	$132.5	$146.4	$275.0	*-$60.3*	-$55.9	-$42.0	$86.5
2033	$191.0	*$154.4*	$130.9	$144.3	$273.4	*-$60.3*	-$60.0	-$46.6	$82.4
2034	$186.9	*$141.4*	$132.9	$146.0	$274.8	*-$60.3*	-$54.0	-$40.9	$87.9
2035	$188.9	*$144.6*	$133.7	$146.7	$275.3	*-$60.3*	-$55.2	-$42.2	$86.3
2036	$183.8	*$133.6*	$130.0	$143.1	$273.3	*-$60.3*	-$53.8	-$40.7	$89.5
2037	$185.5	*$139.2*	$131.4	$144.7	$273.6	*-$60.3*	-$54.1	-$40.8	$88.1
2038	$180.5	*$129.3*	$130.8	$143.8	$273.5	*-$60.3*	-$49.7	-$36.7	$93.0
2039	$187.5	*$142.8*	$131.4	$144.6	$272.6	*-$60.3*	-$56.0	-$42.9	$85.2
2040	$186.9	*$141.4*	$130.2	$143.3	$272.1	*-$60.3*	-$56.7	-$43.5	$85.2
2041	$190.8	*$148.6*	$133.9	$146.9	$274.0	*-$60.3*	-$56.9	-$43.9	$83.2
2042	$188.6	*$147.0*	$133.6	$147.4	$275.6	*-$60.3*	-$55.1	-$41.2	$87.0

Table 12-2: Time Profile of Costs to Society (Millions of 2018$)

	Technology Implementation Costs					Incremental Costs			
Year	**Baseline**	***Option D*[a]**	**Option A (Final Rule)**	**Option B**	**Option C**	***Option D*[a]**	**Option A (Final Rule)**	**Option B**	**Option C**
2043	$189.8	*$152.4*	$131.9	$145.3	$274.0	*-$60.3*	-$57.9	-$44.5	$84.2
2044	$186.5	*$141.3*	$132.1	$145.3	$274.4	*-$60.3*	-$54.4	-$41.3	$87.8
2045	$187.1	*$142.2*	$133.1	$146.2	$275.1	*-$60.3*	-$54.0	-$40.9	$88.0
2046	$186.3	*$140.3*	$131.5	$144.7	$274.0	*-$60.3*	-$54.8	-$41.6	$87.7
2047	$186.9	*$141.9*	$131.5	$144.7	$273.8	*-$60.3*	-$55.4	-$42.2	$86.9
Annualized Costs, 3%	**$309.6**	***$234.3***	**$182.5**	**$206.4**	**$331.1**	***-$130.6***	**-$127.1**	**-$103.2**	**$21.4**
Annualized Costs, 7%	**$347.8**	***$263.0***	**$194.4**	**$221.4**	**$329.6**	***-$154.0***	**-$153.4**	**-$126.4**	**-$18.2**

a. Option D corresponds to the proposed Option 1. EPA did not reanalyze this option for the final rule. All results shown for Option D are based on the 2019 analysis, as detailed in the 2019 BCA (U.S. EPA, 2019a). As such, the values do not reflect changes in the baseline, plant universe, and other analytical inputs for the analysis of Options A, B, and C. Incremental costs for Option D are relative to the 2019 analysis baseline versus the baseline to which Options A, B, and C are compared. For these reasons, the values should not be used for direct comparisons to the final rule.

Source: U.S. EPA Analysis, 2020.

13 Benefits and Social Costs

This chapter compares total monetized benefits and costs for the regulatory options. Benefits and costs are compared on two bases: (1) incrementally for each of the options analyzed as compared to the baseline and (2) incrementally across options. The comparison of benefits and costs also satisfies the requirements of Executive Order 12866: Regulatory Planning and Review and Executive Order 13563: Improving Regulation and Regulatory Review (see Chapter 9 in the *RIA*; U.S. EPA, 2020d).

13.1 Comparison of Benefits and Costs by Option

Chapters 11 and 12 present estimates of the benefits and costs, respectively, for the regulatory options as compared to the baseline. Table 13-1 presents EPA's estimates of benefits and costs of the regulatory options, at 3 percent and 7 percent discount rates, and annualized over 27 years.

Table 13-1: Total Estimated Annualized Benefits and Costs by Regulatory Option and Discount Rate, Compared to Baseline (Millions of 2018$)

Regulatory Option	Total Monetized Benefits[a]		Total Costs
	Low	High	
3% Discount Rate			
Option D[b]	*-$41.0*	*-$86.6*	*-$130.6*
Option A (Final Rule)	-$1.7	$43.3	-$127.1
Option B	$0.3	$35.7	-$103.2
Option C	-$12.4	-$13.4	$21.4
7% Discount Rate			
Option D[b]	*-$13.7*	*-$53.3*	*-$154.0*
Option A (Final Rule)	$6.5	$45.9	-$153.4
Option B	$6.9	$38.1	-$126.4
Option C	-$11.3	-$0.4	-$18.2

a. EPA estimated the air quality-related benefits for Option A. EPA extrapolated estimates of air quality-related benefits for Options B and C from the estimate for Option A that is based on IPM outputs. The Low and High values reflect the lower and upper bound estimates of air quality-related human health benefits. See Chapter 8 for details.

b. Option D corresponds to the proposed Option 1. EPA did not reanalyze this option for the final rule. All results shown for Option D are based on the 2019 analysis, as detailed in the 2019 BCA (U.S. EPA, 2019a). As such, the values do not reflect changes in the baseline, plant universe, and other analytical inputs for the analysis of Options A, B, and C. Total benefits for this option include benefits from changes in cancer incidence associated with disinfection byproducts in drinking water and do not include human health benefits associated with changes in air quality.

Source: U.S. EPA Analysis, 2020.

13.2 Analysis of Incremental Benefits and Costs

In addition to comparing estimated benefits and costs for each regulatory option relative to the baseline, as presented in the preceding section, EPA also estimated the benefits and costs of the options on an incremental basis. The comparison in the preceding section addresses the simple quantitative relationship between estimated benefits and costs for each option and determines whether costs or benefits are greater for a given option and by how much. In contrast, incremental analysis looks at the differential relationship of benefits and costs across options and poses a different question: as increasingly more costly options are considered, by what amount do benefits, costs, and net benefits (*i.e.*, benefits minus costs) change from option to option? Incremental net benefit analysis provides insight into the net gain to society from imposing increasingly more costly requirements.

EPA conducted the incremental net benefit analysis by calculating, for regulatory options A through C, the change in net benefits, from option to option, in moving from the least stringent option to successively more stringent options, where stringency is determined based on total pollutant loads. As described in Chapter 1, the regulatory options differ in the technology basis for different wastestreams. Thus, the difference in benefits and costs across the options derives from the characteristics of the wastestreams controlled by an option, the relative effectiveness of the control technology in reducing pollutant loads, the timing of control technology implementation, and the distribution and characteristics of steam electric power plants and of the receiving reaches.

As reported in Table 13-2, Options A and B have positive benefits and cost savings, with net annual monetized benefits ranging from $125.7 million to $170.1 million under Option A and from $104.0 million to $139.1 million under Option B (3 percent discount rate). Option C has forgone benefits and positive costs, with net annual monetized benefits of -$33.8 million to -$34.9 million using a 3 percent discount rate. Among the regulatory options, the final rule (Option A) results in the highest net annual monetized benefits.

Using a 3 percent discount rate, the incremental net annual monetized benefits of moving from Option A to Option B ranges from -$31.5 million to -$22.0 million. The negative values indicate that net annual monetized benefits are higher for Option A than for Option B. Moving from Option B to Option C, the change is negative, at -$173.7 million to -$137.3 million, indicating that the net annual monetized benefits are higher from Option B than for Option C.

Table 13-2: Analysis of Estimated Incremental Net Benefit of the Regulatory Options, Compared to Baseline and to Other Regulatory Options (Millions of 2018$)

Regulatory Option	Net Annual Monetized Benefits[a,b]		Incremental Net Annual Monetized Benefits[c]	
	Low	High	Low	High
3% Discount Rate				
Option A (Final Rule)	$125.5	$170.4	NA	NA
Option B	$103.5	$138.9	-$22.0	-$31.5
Option C	-$33.8	-$34.8	-$137.3	-$173.7
7% Discount Rate				
Option A (Final Rule)	$159.9	$199.3	NA	NA
Option B	$133.3	$164.5	-$26.6	-$34.8
Option C	$6.9	$17.8	-$126.4	-$146.7

NA: Not applicable for Option A

a. Net benefits are calculated by subtracting total annualized costs from total annual monetized benefits, where both costs and benefits are measured relative to the baseline.

b. EPA estimated the air quality-related benefits for Option A. EPA extrapolated estimates of air quality-related benefits for Options B and C from the estimate for Option A that is based on IPM outputs. See Chapter 8 for details.

c. Incremental net benefits are equal to the difference between net benefits of an option and net benefits of the previous, less stringent option.

Source: U.S. EPA Analysis, 2020.

14 Environmental Justice

Executive Order (EO) 12898 (59 FR 7629, February 11, 1994) requires that, to the greatest extent practicable and permitted by law, each Federal agency must make the achievement of EJ part of its mission. EO 12898 provides that each Federal agency must conduct its programs, policies, and activities that substantially affect human health or the environment in a manner that ensures such programs, policies, and activities do not have the effect of (1) excluding persons (including populations) from participation in, or (2) denying persons (including populations) the benefits of, or (3) subjecting persons (including populations) to discrimination under such programs, policies, and activities because of their race, color, or national origin.

To meet the objectives of EO 12898, EPA examined whether the change in benefits from the regulatory options may be differentially distributed among population subgroups in the affected areas. EPA considered the following factors in this analysis: population characteristics, proximity to affected waters, exposure pathways, cumulative risk exposure, and susceptibility to environmental risk. For example, subsistence fishers rely on self-caught fish for a larger share of their food intake than do recreational fishermen, and as such may incur a larger share of effects arising from the regulatory options.

As described in the following sections, EPA conducted two types of analyses to evaluate the EJ implications of the regulatory options:

1. Summarizing the demographic characteristics of the households living in proximity to steam electric power plants, plant air emissions and surface water discharges, and to the downstream reaches affected by plant discharges; and

2. Analyzing the distribution of human health impacts among minority and/or low-income populations from changes in exposure to pollutants in drinking water, self-caught fish, and the air.

The first analysis provides insight on the distribution of regulatory option effects (*e.g.*, effects on water quality and air pollutant emissions) on communities in proximity to steam electric power plants. The second analysis seeks to provide more specific insight on the distribution of estimated changes in adverse health effects and benefits and to assess whether minority and/or low-income populations incur disproportionately high environmental impacts and/or will be disproportionately excluded from realizing benefits under the regulatory options.

14.1 Socioeconomic Characteristics of Populations Residing in Proximity to Steam Electric Power Plants

For the first analysis, EPA assessed the demographic characteristics of the populations within specified distances of steam electric power plants. The analysis is analogous to the profile EPA developed to support the 2015 rule (U.S. EPA, 2015a) and updated for the 2019 proposal (U.S. EPA, 2019a).

EPA collected population-specific U.S. Census Bureau's American Community Survey (ACS) data on:

- the percent of the population below the poverty threshold,[81] referred to as low-income population for the purpose of this analysis, and
- the population categorized in various racial/ethnic groups, from which EPA calculated the percent of the total population that belongs to a minority racial/ethnic group.[82]

EPA compiled these data for CBGs located within specified distances (*e.g.*, one mile, three miles, 15 miles, 30 miles, and 50 miles) of steam electric power plants and within 50 miles of reaches downstream from steam electric power plant outfalls. EPA compared demographic metrics of these buffer areas to state and national averages to identify communities where EJ concerns may exist. EJ concerns may exist in areas where the percent of the population that is low-income and/or minority is higher than the respective state or national averages.

Specifically, this first analysis considers the spatial distribution of low-income and minority groups to determine whether these groups are more or less represented in the populations living in proximity to steam electric power plants that discharge bottom ash transport water or FGD wastewater. The distance buffers from the steam electric power plants and their associated immediate receiving reaches[83] are denoted below as the "analysis region." Populations within the regions included in the analysis may be affected by steam electric power plant discharges and other environmental impacts in the baseline and by environmental changes resulting from the regulatory options, whether those changes are beneficial or detrimental. If the population within a given region has a larger proportion of low-income or minority than the state average, it may indicate that the regulatory options may affect communities that have been historically exposed to a disproportionate share of environmental impacts and the final rule may thus contribute to redressing or exacerbating existing EJ concerns, depending on the direction of the changes under the regulatory options.

EPA used the U.S. Census Bureau's ACS data for 2013 to 2017 to identify minority and income status at the CBG, analysis region, and state levels. Table 14-1 summarizes the socioeconomic characteristics of the analysis regions defined using radial distances of one, three, 10, 15, 30, and 50 miles from the steam electric power plants.

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[81] Poverty status is based on data from the Census Bureau's American Community Survey which determines poverty status by comparing annual income to a set of dollar values called poverty thresholds that vary by family size, number of children, and the age of the householder.

[82] The racial/ethnic categories are based on available fish consumption data as well as the breakout of ethnic/racial populations in Census data, which distinguishes racial groups within Hispanic and non-Hispanic categories. Minority groups include: African American (non-Hispanic); Asian (non-Hispanic); Native Hawaiian/Pacific Islander (non-Hispanic); American Indian/Alaska Native (non-Hispanic); Other non-Hispanic; Hispanic/Latino.

[83] In this analysis, EPA used the coordinates of each steam electric plant as the basis to define analysis regions using various distance buffers.

Table 14-1: Socioeconomic Characteristics of Communities Living in Proximity to Steam Electric Power Plants and Associated Immediate Receiving Reach, Compared to National Average

Distance from Steam Electric Power Plant	Total Population (Millions)[a]	Percent Minority	Percent Low-Income	Demographic Index[b]
1 mile	0.5	18.4%	13.2%	15.8%
3 miles	1.7	22.8%	13.1%	18.0%
15 miles	25.0	32.9%	13.6%	23.3%
30 miles	87.7	34.7%	13.4%	24.1%
50 miles	199.7	34.4%	13.7%	24.1%
United States	**325.7**	**39.2%**	**14.9%**	**27.1%**

a. Total population is based on the ensemble of CBGs within the specified distance of one or more of the 102 steam electric power plants with non-zero pollutant loads under the baseline or the regulatory options.

b. The demographic index is an average of the two demographic indicators explicitly named in EO 12898: low-income and minority.

Source: U.S. EPA analysis, 2020

As shown in Table 14-1 approximately 500,000 people live within one mile of at least one steam electric power plant currently discharging bottom ash transport water or FGD wastewater to surface waters, approximately 1.7 million live within three miles, and approximately 88 million people live within 30 miles. The socioeconomic statistics show that a smaller fraction of communities that live within all analyzed regions is minority or low-income, when compared to the national average. Of the analyzed regions, communities within 30 or 50 miles of steam electric power plants have the highest demographic index (24.1 percent), which is still lower than the national average (27.1 percent). As one moves farther away from the steam electric power plants, the fraction of the community that is low-income and the percent minority generally increases.

The simple comparison to the national average may not account for important differences, however, between states, particularly given the non-uniform geographical distribution of steam electric power plants across the country. EPA therefore also compared the demographic profile of communities around each plant to that of the states intersected by each analysis region. Table 14-2 summarizes the results of this comparison, as well as the results of comparing the demographic profile of each community to the national average. Although the results in Table 14-1 show that low-income and minority percentages within the various radial distances from steam electric plants are below the national average when considered as a group, the comparison of individual analysis regions around each plant to the national and state averages shows that varying shares of communities within each distance buffer have greater low-income or minority percentages than the national and state averages. For example, although communities within all distance buffers from steam electric plants were, in the aggregate, below the national low-income and minority percentages, there are communities around individual plants with higher proportions of low-income households and/or minority population than the national or respective state averages. Details of this analysis are included in the docket for this final rule (DCN SE09377: *Environmental Justice Analysis: Code, Inputs, and Outputs*). These results highlight the potential for localized differences based on socioeconomic factors, and do not show uniformly higher proportions of low-income and minority population across analysis regions relative to state and national averages.

Table 14-2: Socioeconomic Characteristics of Communities Living in Proximity to Steam Electric Power Plants and Associated Immediate Receiving Reach, Compared to National and State Averages

Distance from Steam Electric Power Plant	Number of Steam Electric Power Plants	Number of Communities[a] Living in Proximity to Steam Electric Plants that…					
		Have a Higher Proportion of Low Income Population	Have a Higher Proportion of Minority Population	Have a Higher Proportion of Low Income and Minority Population	Have a Higher Proportion of Low Income Population	Have a Higher Proportion of Minority Population	Have a Higher Proportion of Low Income and Minority Population
		… than the National Average			… than the State Average[b]		
1 mile	102	40	13	8	39	14	10
3 miles	102	39	10	6	35	14	10
15 miles	102	44	17	10	45	26	15
30 miles	102	49	17	10	39	37	13
50 miles	102	47	21	10	40	39	11

a. In this analysis, a "community" consists of the population associated with the CBGs within the specified distance of each of the 102 steam electric power plants with non-zero pollutant loads under the baseline or the regulatory options.

b. The state average is based on the states intersected by the analysis region around each plant. In cases where an analysis region intersects multiple states, EPA weighted state statistics based on each state's share of the total population within the analysis region.

Source: U.S. EPA analysis, 2020

14.2 Distribution of Human Health Impacts and Benefits

The analysis described in Section 14.1 characterizes populations living in proximity to power plants but does not account for differences across plants in the magnitude of pollutant releases and population exposure.

The second type of analysis looks at the distribution of environmental effects and benefits to further inform understanding of the potential EJ concerns and the extent to which the regulatory options may mitigate or exacerbate these concerns. This analysis allows the Agency to report the distribution of benefits or forgone benefits across population subgroups, including subgroups who may have been historically exposed to a disproportionate share of environmental impacts.

A significant share of the benefits of the regulatory options comes from the small estimated changes in the discharges of harmful pollutants to surface waters and associated changes in drinking water quality[84] and fish tissue contamination, and from small estimated changes in air emissions. The sections below discuss the distribution of health effects for these pathways.

14.2.1 Socioeconomic Characteristics of Populations Affected by Changes in Pollutant Levels in Drinking Water Sources

EPA estimated the changes in halogen concentrations in PWS source waters affected by steam electric power plants' discharges, and characterized the populations served by the PWS directly or indirectly affected by these changes. Chapter 4 discusses the analysis and the approach used to identify the affected population

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[84] Although EPA did not monetize the benefits of changes in treated drinking water quality, the Agency did look at the distribution of changes in source water quality used by PWS and uses these results here to assess impacts to different communities for this pathway.

based on the county or tribal service areas. That analysis indicates that at the national level, source water halogen levels decrease in the long term under the final rule (Option A), as well as under Options B and C.[85]

Table 14-3 summarizes the estimated population potentially affected by changes in drinking water quality resulting from changes in halogen levels in source waters. The analysis is conducted at the county level and compares the demographic profile of the affected counties (based on the service areas of affected PWS) to that of the respective states where each county is located. More than 31 million people, across 286 counties and 27 states, are estimated to be potentially affected by the small estimated changes in source water quality under the regulatory options. Most of the 27 states have PWS that serve at least one county with higher proportions of low-income and/or minority populations than the state average, indicating a potential for localized effects. Overall, however, counties in service areas potentially affected by changes in source water quality are not uniformly more low-income and/or minority than their state averages. Details of this analysis are included in the docket for this final rule (DCN SE09377: *Environmental Justice Analysis: Code, Inputs, and Outputs*).

Table 14-3: Socioeconomic Characteristics of Counties in Service Areas of Potentially Affected PWS, Compared to State Average

State	Number of Counties in Service Areas of Potentially Affected PWS	Population Served by Affected PWS[a]	Number of Counties in Service Areas of Potentially Affected PWS that…		
			Have a Higher Proportion of Low Income Population	Have a Higher Proportion of Minority Population	Have a Higher Proportion of Low Income and Minority Population
			… than the State Average		
Alabama	24	1,668,000	11	8	6
Arizona	1	9,000	1	1	1
Delaware	1	309,000	0	1	0
District of Columbia	1	649,000	0	0	0
Georgia	12	701,000	7	3	2
Illinois	13	715,000	6	1	1
Indiana	4	201,000	1	0	0
Iowa	5	269,000	4	1	1
Kansas	7	825,000	3	1	1
Kentucky	27	1,469,000	6	6	1
Louisiana	8	992,000	2	5	1
Maryland	9	4,155,000	3	3	1
Massachusetts	2	376,000	0	1	0
Michigan	8	3,440,000	2	4	2
Missouri	16	2,615,000	6	3	2
Nebraska	5	573,000	2	1	1
North Carolina	11	1,555,000	6	4	3
North Dakota	5	33,000	1	0	0
Ohio	9	1,183,000	5	1	1
Oklahoma	3	62,000	1	0	0
Pennsylvania	16	3,860,000	4	3	1
South Carolina	12	1,000,000	5	3	3

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[85] Halogen levels increase in the short term under Options A and B before decreasing in the long term and decrease under Option C in both the short and long term. See Section 4.1 for details.

Table 14-3: Socioeconomic Characteristics of Counties in Service Areas of Potentially Affected PWS, Compared to State Average

State	**Number of Counties in Service Areas of Potentially Affected PWS**	**Population Served by Affected PWS[a]**	**Number of Counties in Service Areas of Potentially Affected PWS that… Have a Higher Proportion of Low Income Population … than the State Average**	**Have a Higher Proportion of Minority Population**	**Have a Higher Proportion of Low Income and Minority Population**
South Dakota	43	187,000	18	13	12
Tennessee	20	2,116,000	11	3	1
Utah	2	1,000	1	0	0
Virginia	10	2,345,000	5	9	4
West Virginia	12	305,000	3	5	2
Total	**286**	**31,610,000**	**114**	**80**	**47**

[a] The affected population is based on the total population served reported by SDWIS for affected PWS within each state. However, not all reported individuals may reside within the designated county and state in cases where a PWS service area extends over multiple counties (or states).

Source: U.S. EPA analysis, 2020

Table 14-4 summarizes the estimated tribal area population potentially affected by small changes in drinking water quality as a result of steam electric power plant discharges. The analysis compares the demographic profile of the affected tribal areas to that of the state where they are located. As shown in the table, affected tribal areas consistently have a higher minority population than the state average; half of the tribal areas have minority population percentages greater than 90 percent.

Table 14-4: Socioeconomic Characteristics of Affected Tribal Areas, Compared to State Average

Affected Tribal Areas	**States with Affected Tribal Areas**	**Total Population**			**Percent Minority**		**Percent Low-Income**		**Demographic Index**	
		Affected Population[a]	**Total for Tribal Area**	**State(s)**	**Tribal Area**	**State**	**Tribal Area**	**State**	**Tribal Area**	**State**
Crow Creek Reservation	SD	1,873	2,151	855,444	94.9%	17.3%	41.4%	13.9%	68.2%	15.6%
Lake Traverse Reservation	ND; SD	230	10,967	1,600,919	48.1%	15.9%	19.4%	12.6%	33.8%	14.3%
Lower Brule Reservation	SD	2,116[b,c]	1,594	855,444	94.0%	17.3%	42.7%	13.9%	68.4%	15.6%
Navajo Nation	AZ; NM; UT	1,190	175,005	11,888,715	98.3%	41.6%	40.5%	16.1%	69.4%	28.8%
Pine Ridge Reservation	NE; SD	8,713	19,779	2,749,365	89.5%	19.3%	50.4%	12.6%	70.0%	16.0%
Rosebud Indian Reservation	SD	5,619	11,354	855,444	92.0%	17.3%	54.3%	13.9%	73.2%	15.6%
Standing Rock Reservation	ND; SD	6,839	8,616	1,600,919	79.2%	15.9%	42.3%	12.6%	60.8%	14.3%
Yankton Reservation	SD	1,064	6,676	855,444	50.4%	17.3%	27.3%	13.9%	38.9%	15.6%

a. The affected population is based on the population served by the PWS, as reported in SDWIS. In some cases, the PWS serves both the tribal area and surrounding counties.

b. PWS ID 84690026 serves several reservations and counties. Therefore, SDWIS reported population served was equally distributed over the three reservations served: Lower Brule Reservation, Pine Ridge Reservation, and Rosebud Indian Reservation.

c. PWS ID 84690441 serves the Lower Brule Reservation and surrounding South Dakota counties. As a result, the SDWIS reported population served exceeds the Census reported total population of the reservation. The affected percentage of tribal area was adjusted to 80 percent to reflect that the majority of the reservation is likely served by the affected PWS.

Source: U.S. EPA analysis, 2020

14.2.2 Socioeconomic Characteristics of Populations Affected by Changes in Exposure to Pollutants via the Fish Ingestion Pathway

This section first evaluates the socioeconomic characteristics of communities within 50 miles of immediate reaches that receive discharges from steam electric power plants, as well as of downstream reaches.[86] The section then presents the distribution of EPA's quantified human health effects resulting from the small estimated changes in exposure to selected pollutants via consumption of self-caught fish.[87] Chapter 5 provides more details on the approach used to identify the affected recreational and subsistence fisher population, estimate exposure based on race and ethnicity-specific data, quantify health effects, and monetize benefits.

As shown in Table 14-5 and Table 14-6 (for Period 1 and Period 2, respectively), the community living in proximity to reaches with increases in pollutant levels under Options A, B, and C has a smaller proportion of low-income and minority population than the national average. For many pollutants, the community living in proximity to reaches with decreases or no change in pollutant levels under Options A, B, and C has a greater proportion of low-income and minority population than the national average in many cases.

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[86] The analysis focuses on selected pollutants that have at least one exceedance of human health criteria across the options and periods (antimony, arsenic, cadmium, cyanide, lead, manganese, and thallium) plus mercury to provide additional insight on the distribution of benefits discussed in Chapter 5. Table 5-7 provides additional information on reaches with exceedances of human health criteria.

[87] The first analysis defines "communities in proximity to reaches" as the aggregate populations residing in CBGs within 50 miles of all reaches within 300 km of steam electric power plant outfalls. This analysis provides total population and does not make adjustments for the fraction of this population that consumes self-caught fish.

Table 14-5: Socioeconomic Characteristics of Communities Living in Proximity to Reaches with Changes to Selected Pollutant Concentrations under the Regulatory Options, Compared to Baseline (Period 1)

Pollutant	Changes in Concentrations	Number of Reaches			Percent Minority			Percent Low-Income			Demographic Index		
		Option A (Final Rule)	Option B	Option C	Option A (Final Rule)	Option B	Option C	Option A (Final Rule)	Option B	Option C	Option A (Final Rule)	Option B	Option C
Antimony	Decreases	0	0	811	0.0%	0.0%	37.3%	0.0%	0.0%	15.0%	0.0%	0.0%	26.2%
	No changes	1,403	1,346	804	35.8%	35.9%	25.6%	15.1%	15.1%	14.7%	25.5%	25.5%	20.2%
	Increases	9,051	9,108	8,839	33.1%	33.1%	33.2%	14.0%	14.0%	14.0%	23.6%	23.6%	23.6%
Arsenic	Decreases	0	0	1,329	0.0%	0.0%	37.5%	0.0%	0.0%	14.7%	0.0%	0.0%	26.1%
	No changes	1,403	1,346	804	35.8%	35.9%	25.6%	15.1%	15.1%	14.7%	25.5%	25.5%	20.2%
	Increases	9,051	9,108	8,321	33.1%	33.1%	32.9%	14.0%	14.0%	14.0%	23.6%	23.6%	23.5%
Cadmium	Decreases	0	0	2,854	0.0%	0.0%	38.1%	0.0%	0.0%	13.9%	0.0%	0.0%	26.0%
	No changes	1,403	1,346	804	35.8%	35.9%	25.6%	15.1%	15.1%	14.7%	25.5%	25.5%	20.2%
	Increases	9,051	9,108	6,796	33.1%	33.1%	31.0%	14.0%	14.0%	14.3%	23.6%	23.6%	22.7%
Cyanide	Decreases	0	0	4,729	0.0%	0.0%	35.2%	0.0%	0.0%	14.3%	0.0%	0.0%	24.8%
	No changes	5,711	5,711	1,114	35.0%	35.0%	34.7%	14.0%	14.0%	15.2%	24.5%	24.5%	25.0%
	Increases	524	524	392	29.8%	29.8%	27.4%	16.6%	16.6%	11.6%	23.2%	23.2%	19.5%
Lead	Decreases	0	0	960	0.0%	0.0%	40.2%	0.0%	0.0%	15.0%	0.0%	0.0%	27.6%
	No changes	1,403	1,346	804	35.8%	35.9%	25.6%	15.1%	15.1%	14.7%	25.5%	25.5%	20.2%
	Increases	9,051	9,108	8,690	33.1%	33.1%	32.5%	14.0%	14.0%	13.9%	23.6%	23.6%	23.2%
Manganese	Decreases	0	0	3,052	0.0%	0.0%	37.3%	0.0%	0.0%	13.9%	0.0%	0.0%	25.6%
	No changes	1,403	1,346	804	35.8%	35.9%	25.6%	15.1%	15.1%	14.7%	25.5%	25.5%	20.2%
	Increases	9,051	9,108	6,598	33.1%	33.1%	31.3%	14.0%	14.0%	14.3%	23.6%	23.6%	22.8%
Mercury	Decreases	0	0	331	0.0%	0.0%	37.6%	0.0%	0.0%	15.9%	0.0%	0.0%	26.8%
	No changes	1,287	1,259	794	32.2%	33.9%	26.0%	16.0%	15.6%	14.7%	24.1%	24.8%	20.4%
	Increases	9,167	9,204	9,329	33.7%	33.5%	33.5%	14.0%	13.9%	14.0%	23.9%	23.7%	23.8%
Thallium	Decreases	0	0	3,846	0.0%	0.0%	36.2%	0.0%	0.0%	14.2%	0.0%	0.0%	25.2%
	No changes	1,403	1,346	804	35.8%	35.9%	25.6%	15.1%	15.1%	14.7%	25.5%	25.5%	20.2%
	Increases	9,051	9,108	5,804	33.1%	33.1%	31.6%	14.0%	14.0%	14.1%	23.6%	23.6%	22.9%
United States					**39.2%**			**14.9%**			**27.1%**		

Source: U.S. EPA analysis, 2020

Table 14-6: Socioeconomic Characteristics of Communities Living in Proximity to Reaches with Changes to Selected Pollutant Concentrations under the Regulatory Options, Compared to Baseline (Period 2)

Pollutant	Changes in Concentrations	Number of Reaches			Percent Minority			Percent Low-Income			Demographic Index		
		Option A (Final Rule)	Option B	Option C	Option A (Final Rule)	Option B	Option C	Option A (Final Rule)	Option B	Option C	Option A (Final Rule)	Option B	Option C
Antimony	Decreases	292	292	2,966	56.8%	56.8%	36.6%	17.5%	17.5%	15.6%	37.2%	37.2%	26.1%
	No changes	2,062	2,062	1,464	37.0%	37.0%	36.4%	14.0%	14.0%	13.6%	25.5%	25.5%	25.0%
	Increases	8,100	8,100	6,024	31.3%	31.3%	31.2%	14.1%	14.1%	13.6%	22.7%	22.7%	22.4%
Arsenic	Decreases	588	588	4,993	52.0%	52.0%	34.3%	16.9%	16.9%	15.0%	34.5%	34.5%	24.7%
	No changes	2,062	2,062	1,464	37.0%	37.0%	36.4%	14.0%	14.0%	13.6%	25.5%	25.5%	25.0%
	Increases	7,804	7,804	3,997	31.4%	31.4%	31.3%	14.1%	14.1%	13.5%	22.8%	22.8%	22.4%
Cadmium	Decreases	1,150	1,351	5,463	37.2%	42.1%	37.2%	15.9%	13.3%	14.5%	26.6%	27.7%	25.9%
	No changes	2,062	2,062	1,464	37.0%	37.0%	36.4%	14.0%	14.0%	13.6%	25.5%	25.5%	25.0%
	Increases	7,242	7,041	3,527	31.8%	30.5%	24.5%	14.0%	14.4%	13.8%	22.9%	22.5%	19.2%
Cyanide	Decreases	1,895	2,096	5,841	32.8%	36.4%	35.6%	15.8%	14.1%	14.5%	24.3%	25.3%	25.1%
	No changes	4,340	4,139	394	35.0%	33.8%	28.5%	13.8%	14.3%	12.4%	24.4%	24.1%	20.5%
	Increases	0	0	0	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Lead	Decreases	513	513	3,612	55.0%	55.0%	35.9%	17.2%	17.2%	15.6%	36.1%	36.1%	25.8%
	No changes	2,062	2,062	1,464	37.0%	37.0%	36.4%	14.0%	14.0%	13.6%	25.5%	25.5%	25.0%
	Increases	7,879	7,879	5,378	31.3%	31.3%	31.2%	14.1%	14.1%	13.5%	22.7%	22.7%	22.4%
Manganese	Decreases	1,711	1,912	5,841	35.3%	39.5%	36.7%	15.9%	13.9%	14.5%	25.6%	26.7%	25.6%
	No changes	2,062	2,062	1,464	37.0%	37.0%	36.4%	14.0%	14.0%	13.6%	25.5%	25.5%	25.0%
	Increases	6,681	6,480	3,149	31.8%	30.4%	24.7%	13.9%	14.3%	13.8%	22.9%	22.4%	19.3%
Mercury	Decreases	588	588	4,740	52.0%	52.0%	35.4%	16.9%	16.9%	15.4%	34.5%	34.5%	25.4%
	No changes	2,062	2,062	1,464	37.0%	37.0%	36.4%	14.0%	14.0%	13.6%	25.5%	25.5%	25.0%
	Increases	7,804	7,804	4,250	31.4%	31.4%	30.7%	14.1%	14.1%	13.2%	22.8%	22.8%	22.0%
Thallium	Decreases	1,150	1,351	5,579	37.2%	42.1%	37.0%	15.9%	13.3%	14.5%	26.6%	27.7%	25.8%
	No changes	2,062	2,062	1,464	37.0%	37.0%	36.4%	14.0%	14.0%	13.6%	25.5%	25.5%	25.0%
	Increases	7,242	7,041	3,411	31.8%	30.5%	24.4%	14.0%	14.4%	13.8%	22.9%	22.5%	19.1%
United States					**39.2%**			**14.9%**			**27.1%**		

Source: U.S. EPA analysis, 2020

As described in Chapter 5, EPA quantified the distribution of human health effects associated with lead and mercury exposure among two types of fishers (recreational and subsistence) and their families.[88] Because quantified health effects are limited to changes in IQ losses from exposure to lead and mercury, the following discussion focuses on the population of infants and children ages 0 to 7 potentially exposed to steam electric pollutants via consumption of contaminated fish. The quantified effects relative to the baseline are small, overall.

Table 14-7 summarizes the estimated number of children ages 0 to 7 exposed to lead and infants exposed to mercury in-utero via the consumption of self-caught fish in the total population of fishers and in population subgroups that may be indicative of EJ concerns.[89] As shown in the table, of the approximately 1.6 million children ages 0 to 7 potentially exposed to steam electric power plant wastewater pollutants through fish tissue consumption, an estimated 15.9 percent are low-income, 64.0 percent are minority, and 11.1 percent are both low-income and minority. Overall, 68.8 percent of potentially exposed children are categorized in at least one or more EJ subgroup based on household income or race/ethnicity, while 31.2 percent are neither minority nor low-income.[90] EPA estimates that approximately 151,000 infants are potentially exposed to mercury in-utero. The potentially exposed infant population and its characteristics are based on the number of women of child-bearing age (15 to 44 years old) multiplied by the average, ethnic group-based fertility rates, and their socioeconomic characteristics.

Table 14-7: Characteristics of Children Potentially Exposed to Steam Electric Power Plant Pollutants via Consumption of Self-caught Fish

Subgroup	Minority		Non-Minority		Total	
Lead (Children Ages 0-7)						
Low-income	179,693	11.1%	77,559	4.8%	257,252	15.9%
Minority	853,552	52.8%	504,825	31.2%	1,358,378	84.1%
Total	**1,033,245**	**64.0%**	**582,384**	**36.0%**	**1,615,629**	**100.0%**
Mercury (Infants)[a]						
Low-income	25,710	11.4%	10,294	4.6%	36,003	16.0%
Minority	125,393	55.6%	64,140	28.4%	189,534	84.0%
Total	**151,103**	**67.0%**	**74,434**	**33.0%**	**225,537**	**100.0%**

a. Potentially exposed infant population is based on the number of women of child-bearing age (15 to 44 years old) multiplied by the average, ethnic group-based fertility rates. Therefore, it reflects socio-demographic characteristics of women of child-bearing age.

Source: U.S. EPA Analysis, 2020

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[88] As discussed in Chapter 5, the regulatory options did not result in material changes in arsenic-related health effects.

[89] Because data on socioeconomic characteristics of freshwater fishers are not available at the CBG level, EPA used the same socioeconomic characteristics for fishers as those of the general population residing within a 50-mile radius from the affected reaches.

[90] In the discussion, EPA uses minority/low-income percentages based on the population potentially exposed to lead because the population potentially exposed to lead (children aged 0-7) encompasses the population potentially exposed to mercury (infants).

The distribution of adverse health effects is a function of the characteristics of the affected population (Table 14-7), including age and sex,[91] ethnicity-specific exposure factors,[92] and water quality. Table 14-8 shows the distribution of changes in adverse health effects under each of the regulatory options for minority and low-income subgroups, as well as non-minority and not low-income subgroups. The first two subgroups are the primary interest of this analysis as potentially indicative of EJ concerns.

The quantified effects relative to the baseline are small, both overall and for the subgroups. The distribution of the small changes in IQ points across the subgroups shows that the changes (positive or negative) estimated over the total population of exposed children predominantly affect children in the minority subgroup.

In the analysis of health benefits for the fish ingestion pathway (see Chapter 5), EPA assumed that 5 percent of the exposed population are subsistence fishers, and that the remaining 95 percent are recreational fishers. Subsistence fishers consume more self-caught fish than recreational fishers and can therefore be expected to experience higher health risks associated with exposure to steam electric pollutants in fish tissue. Table 14-9 shows the distribution of changes in adverse health effects among children in households of subsistence fishers and recreational fishers.

Here also, the quantified effects relative to the baseline are small, both overall and across fisher subgroups. The distribution of changes in IQ points across children of the two fisher subgroups shows that effects on children in subsistence fishers’ households from exposure to lead-contaminated fish tissue are disproportionate to their share of the affected population (see Table 14-9 for details). While children from subsistence fishers’ households account for 5 percent of the total exposed populations, they incur 6.4 percent of the effects (positive or negative) under the regulatory options, compared to baseline.

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[91] Some adverse health effects are analyzed only for individuals in certain age groups. For example, IQ point decrements from exposure to lead are calculated for children 0 to 7 years old and the baseline exposure therefore depends on the number of children within this age group in the affected population in each socioeconomic subgroup. IQ point decrements from exposure to mercury are calculated for infants born within the analysis period and baseline exposure depends on the number of women of childbearing age (and fertility rates) in the affected population.

[92] Ethnicity-specific factors that determine exposure to pollutants in fish tissue include the assumed fish consumption rates and average fertility rate. For example, Asian/Pacific Islander fishers have fish consumption rates that are 1.4 times and 1.9 times those of While (non-Hispanic) fishers for recreational and subsistence fishing modes, respectively.

Table 14-8: Estimated Distribution of IQ Point Changes from Lead and Mercury Exposure Via Self-caught Fish Consumption Under the Regulatory Options, Compared to Baseline (2021 to 2047)

Pollutant and Population	Regulatory Option	Percent Minority		Percent Low-Income		Percent Non-Minority, Not Low-Income		Total	
		Positive IQ Change (% of Exposed Population)	Negative IQ Change (% of Exposed Population)	Positive IQ Change (% of Exposed Population)	Negative IQ Change (% of Exposed Population)	Positive IQ Change (% of Exposed Population)	Negative IQ Change (% of Exposed Population)	Positive IQ Change (% of Exposed Population)	Negative IQ Change (% of Exposed Population)
% of Children Ages 0 to 7 Exposed to Lead		64.0%		15.9%		31.2%		100.0%	
Children Exposed to Lead[a,b]	*Option D[c]*	– –	– –	– –	– –	– –	– –	*<1.30 (0.1%)*	*-3.89 (66.1%)*
	Option A (Final Rule)	0 (0.0%)	-18 (64.0%)	0 (0.0%)	-5 (15.9%)	0 (0.0%)	>-1 (31.2%)	0 (0.0%)	-19 (100.0%)
	Option B	0 (0.0%)	-11 (64.0%)	0 (0.0%)	-3 (15.9%)	0 (0.0%)	>-1 (31.2%)	0 (0.0%)	-11 (100.0%)
	Option C	13 (8.8%)	-1 (55.2%)	3 (2.2%)	0 (13.7%)	0 (0.0%)	>-1 (31.2%)	13 (8.8%)	-2 (91.2%)
% of Infants Exposed to Mercury In-utero		67.0%		16.0%		28.4%		100.0%	
Infants Exposed to Mercury[a,b]	*Option D[c]*	– –	– –	– –	– –	– –	– –	*0 0*	*-411 (100%)*
	Option A (Final Rule)	122 (35.9%)	-201 (31.1%)	34 (6.3%)	-46 (9.7%)	0 (0.0%)	-105 (28.4%)	122 (35.9%)	-323 (64.1%)
	Option B	151 (35.9%)	-190 (31.1%)	38 (6.3%)	-42 (9.7%)	0 (0.0%)	-90 (28.4%)	151 (35.9%)	-296 (64.1%)
	Option C	199 (36.1%)	-78 (30.9%)	46 (6.6%)	-15 (9.4%)	0 (0.0%)	-43 (28.4%)	199 (36.1%)	-128 (63.9%)

– Not estimated

a. Negative values represent forgone benefits and positive values represent realized benefits.

b. EPA estimates that options A and B will result in an overall increase in exposure to lead and mercury and thus an increase in IQ losses (*i.e.*, negative changes). Option C results in an overall decrease in IQ losses (*i.e.,* positive changes).

c. Option D corresponds to the proposed Option 1. EPA did not reanalyze this option for the final rule. All results shown for Option D are based on the 2019 analysis, as detailed in the 2019 BCA (U.S. EPA, 2019a). As such, the values do not reflect changes in the baseline, plant universe, and other analytical inputs for the analysis of Options A, B, and C. Only the total value is provided due to changes in the presentation of the EJ subgroups.

Source: U.S. EPA Analysis, 2020

Table 14-9: Estimated Distribution of Changes in IQ Point Changes from Lead and Mercury Exposure Via Self-caught Fish Consumption under the Regulatory Options, Compared to Baseline, by Fishing Mode (2021 to 2047)

Pollutant and Exposed Population	Regulatory Option	Subsistence Fishers (5% of Population)		Recreational Fishers (95% of Population)		Total	
		Positive IQ Change (% of Exposed Population)	Negative IQ Change (% of Exposed Population)	Positive IQ Change (% of Exposed Population)	Negative IQ Change (% of Exposed Population)	Positive IQ Change (% of Exposed Population)	Negative IQ Change (% of Exposed Population)
Children Exposed to Lead[a]	*Option D[c]*	*<1 (0.1%)*	*-3 (6.5%)*	*0 (0.0%)*	*-1 (59.6%)*	*<1 (0.1%)*	*-4 (66.1%)*
	Option A (Final Rule)	0 (0.0%)	>-1 (6.4%)	0 (0.0%)	-18 (93.6%)	0 (0.0%)	-19 (100.0%)
	Option B	0 (0.0%)	>-1 (6.4%)	0 (0.0%)	-11 (93.6%)	0 (0.0%)	-11 (100.0%)
	Option C	0 (0.0%)	>-1 (6.4%)	13 (8.8%)	-1 (84.8%)	13 (8.8%)	-2 (91.2%)
Infants Exposed to Mercury[a,b]	*Option D[c]*	*0 (0.0%)*	*-71 (17.3%)*	*0 (0.0%)*	*340 (82.7%)*	*0 (0.0%)*	*-411 (100.0%)*
	Option A (Final Rule)	20 (2.3%)	-55 (4.1%)	102 (33.6%)	-268 (60.0%)	122 (35.9%)	-323 (64.1%)
	Option B	26 (2.3%)	-51 (4.1%)	126 (33.6%)	-245 (60.0%)	151 (35.9%)	-296 (64.1%)
	Option C	34 (2.3%)	-22 (4.1%)	165 (33.8%)	-106 (59.8%)	199 (36.1%)	-128 (63.9%)

a. Negative values represent forgone benefits and positive values represent realized benefits.

c. Option D corresponds to the proposed Option 1. EPA did not reanalyze this option for the final rule. All results shown for Option D are based on the 2019 analysis, as detailed in the 2019 BCA (U.S. EPA, 2019a). As such, the values do not reflect changes in the baseline, plant universe, and other analytical inputs for the analysis of Options A, B, and C.

Source: U.S. EPA Analysis, 2020

14.2.3 Socioeconomic Characteristics of Populations Affected by Changes in Exposure to Air Pollutants

EPA quantified the human health effects resulting from the small estimated changes in EGU emissions of NO_X, SO_2, and $PM_{2.5}$ under the final rule (Option A), compared to baseline. This analysis, which is detailed in Chapter 8, included estimated changes in the incidence of adverse health effects resulting from exposure to $PM_{2.5}$ and ozone using BenMAP-CE. To provide insight into the potential EJ implications of these changes, EPA reviewed the distribution of changes in adverse health effects projected by BenMAP-CE across counties and, using ACS data, summarized the socioeconomic characteristics of the populations living in the counties projected to see changes in the number of cases of adverse health outcomes during the period of analysis (2021-2047). This analysis entailed: (1) exporting county-level projected health outcomes for each analysis year; (2) summing cases in each county over the 27-year analysis period; (3) categorizing counties according to whether they see a net increase or net decrease in adverse health outcomes over the period of analysis under the final rule as compared to the baseline, and (4) summarizing the socioeconomic characteristics of people living in the counties.

This analysis reflects the geographical distribution of air quality changes (both in terms of direction and magnitude of the changes) and differences in the socioeconomic characteristics of the counties that see these projected changes in air quality. EPA's approach to characterizing risks among these subgroups did not account for differences in susceptibility or vulnerability among subgroups according to income or race/ethnicity by, for example, using concentration-response relationships that account for population race or ethnicity. The approach distributes the estimated changes in the number of adverse health outcomes within a county uniformly across all people residing within the county.

Table 14-10 summarizes the estimated distribution of selected health outcomes quantified in BenMAP-CE. The presentation is similar to that used above for characterizing populations living near reaches with improving or degrading water quality, except that in this analysis, the analyzed population corresponds to the population of the counties with net total increase or net total decrease in the number of projected adverse health outcomes due to EGU emissions changes and resulting changes in air quality under the final rule as compared to the baseline. As shown in Table 14-10, a larger share of the U.S. population see positive benefits (a net *reduction* in adverse health outcomes) than forgone benefits (a net *increase* in adverse health outcomes) under the final rule.

Minority populations are estimated to accrue a disproportionate share of the benefits from the final rule; whereas 39.2 percent of the U.S. population is minority, between 42.1 percent and 43.8 percent of the net avoided adverse health outcomes are estimated to accrue to minority populations. Conversely, minority populations see an estimated 32.3 percent to 35.2 percent of the net increases in adverse outcomes, which is less than their 39.2 percent share of the general U.S. population.

The distribution of net changes in health outcomes relative to income is more uniform. The shares of net changes in adverse health outcomes (increase or decrease) accruing to the low-income subgroup approach the 14.9 percent of the general U.S. population that is low-income. However, a slightly larger share of the benefits (*i.e.*, net decrease in adverse health outcomes), ranging between 15.1 and 15.4 percent, accrues to the low-income subgroup than the subgroup's representation in the general U.S. population (14.9 percent).

Table 14-10: Socioeconomic Characteristics of Populations Projected to see Net Increases and Decreases in Adverse Health Outcomes from Changes in Exposure to $PM_{2.5}$ and Ground-level Ozone Under the Final Rule, Compared to Baseline, in 2021-2047

Quantified Health Outcome	Net Direction of Change[a]	% of Total Population	% of Change Accruing to Minority Population	% of Change Accruing to Low Income Population
Premature mortality[b]	Net Increase	46.9%	33.4%	13.8%
	Net Decrease	53.1%	42.8%	15.3%
Non-fatal heart attacks (age > 18)	Net Increase	45.9%	33.8%	13.8%
	Net Decrease	54.1%	42.2%	15.3%
Hospital admissions—respiratory (all ages)	Net Increase	46.0%	32.3%	13.7%
	Net Decrease	54.0%	43.5%	15.4%
Hospital admissions—cardiovascular (age >20)	Net Increase	45.9%	33.9%	13.8%
	Net Decrease	54.1%	42.1%	15.3%
Emergency room visits for asthma (all ages)	Net Increase	47.9%	33.2%	14.0%
	Net Decrease	52.1%	43.1%	15.2%
Acute bronchitis (age 8-12)	Net Increase	46.0%	33.8%	13.8%
	Net Decrease	54.0%	42.2%	15.3%
Lower respiratory symptoms (age 7-14)	Net Increase	46.0%	33.8%	13.8%
	Net Decrease	54.0%	42.2%	15.3%
Upper respiratory symptoms (asthmatics age 9-11)	Net Increase	46.0%	33.8%	13.8%
	Net Decrease	54.0%	42.2%	15.3%
Exacerbated asthma (asthmatics age 6-18)	Net Increase	52.4%	33.5%	14.0%
	Net Decrease	47.6%	43.8%	15.3%
Lost work days (age 18-65)	Net Increase	46.0%	33.8%	13.8%
	Net Decrease	54.0%	42.2%	15.3%
Minor restricted-activity days (age 18-65)	Net Increase	47.3%	33.0%	13.9%
	Net Decrease	52.7%	43.2%	15.3%
School absence days (age 5–17)	Net Increase	54.3%	35.2%	14.2%
	Net Decrease	45.7%	42.1%	15.1%
Subgroup as % of U.S. Population			**39.2%**	**14.9%**

a. Reflects the net direction of total changes in cases over the period of 2021 through 2047. Some individual years may have negative changes and other years may have positive changes.

b. Reported percentages for premature mortality reflect the upper bound of mortality incidence estimates from Jerret et al. (2009) and Lepeule et al. (2012). The difference between the percentages for the upper bound and lower bound (not reported) of mortality incidence estimates is very small (<0.3%).

Source: U.S. EPA analysis, 2020

14.3 EJ Analysis Findings

Overall, the various analyses show that environmental changes under the regulatory options analyzed, including the final rule, may affect minority and/or low income populations to different degrees across environmental media, exposure pathways, and over time, but the effects (positive or negative) of the changes will be small.

Communities living near steam electric power plants (*i.e.*, up to 50 miles) tend to have a lower proportion of low-income households and minority population than the national average, when considered in the aggregate, but there may be localized EJ considerations for some communities near individual plants that have higher proportions of low-income or minority populations than the national and/or state average (see Table 14-2).

EPA's analysis considered the distribution of effects on populations near both immediate and downstream reaches, in downstream PWS service areas, and in adjacent airsheds to assess whether low-income and/or minority populations may be disproportionately affected by changes under the final rule (Option A) and other regulatory options. The analysis shows that the EJ population subgroups are not excluded from the benefits associated with the regulatory options, including the final rule. For example, projected air quality changes under the final rule (Option A) may disproportionately benefit minority and low-income populations based on the socioeconomic characteristics of populations of counties with changes in $PM_{2.5}$ and ozone levels during the period of analysis. Additionally, estimated foregone benefits related to water quality may disproportionately affect minority and subsistence fisher populations. However, the magnitude of the changes (positive and negative) and associated benefits (including foregone benefits) is small, relative to the baseline, both overall across the exposed population, and across socioeconomic and fisher subgroups.

14.4 Limitations and Uncertainties

This EJ analysis incorporates the limitations and uncertainties associated with the human health effects analyses (see Chapter 4, Chapter 5, and Chapter 8) regarding pollutant exposure, and incidence of adverse health outcomes. In addition, the EJ analysis embeds uncertainty derived from the application of uniform inputs across the estimated population exposed to pollutant discharges when factors may instead vary across socioeconomic characteristics. In summary, use of average values across the entire population of the United States (or within a state or a county associated with a PWS service area) instead of inputs that reflect specific socioeconomic factors may over- or understate inequities present in the baseline and the differential impacts or benefits to low-income or minority populations from changes due to the regulatory options.

Note that the effect on benefits estimates indicated in the second column of the table refers to the magnitude of the benefits rather than the direction (*i.e.*, a source of uncertainty that tends to underestimate benefits indicates expectation for larger forgone benefits or for larger realized benefits).

Table 14-11: Limitations and Uncertainties in EJ Analysis

Uncertainty/Limitation	Effect on EJ Analysis	Notes
EPA estimated that all fishers travel up to 50 miles.	Uncertain	Certain EJ subpopulations may tend to fish closer to home (*e.g.*, low-income and subsistence fishers). To the extent that these people fish predominantly from waters receiving discharges from steam electric power plants, they may be exposed to relatively higher concentrations of pollutants. Conversely, people who live farther from steam electric power plants may predominantly fish from waters not affected by pollutants in steam electric power plant discharges and be exposed to relatively lower concentrations of pollutants.
EPA estimated that subsistence fishers are 5 percent of all fishers, and applied this estimate uniformly across all socioeconomic groups.	Underestimate	A relatively higher share of EJ groups may be subsistence fishers. This could increase inequities in the baseline and affect the extent to which the regulatory options may increase or decrease these inequities.
EPA applied uniform fishing participation rates, FCA responses, and catch and release practices across the entire population.	Uncertain	Differences in behavior across socioeconomic groups may result in a different distribution of baseline and regulatory option impacts.

Table 14-11: Limitations and Uncertainties in EJ Analysis

Uncertainty/Limitation	Effect on EJ Analysis	Notes
EPA used the counties served by PWS, as reported in the SDWIS database, as representative of the population potentially affected by changes in halogenated DBPs due to steam electric power plant discharges.	Uncertain	Counties and tribal areas can be served by multiple PWS and some PWS serve people across multiple counties, such that the affected population may have different socioeconomic characteristics.
EPA used the SDWIS database to identify counties served by affected PWS. For any PWS IDs without any associated county information, EPA used the PWS Name and the PWS latitude and longitude to identify associated tribal areas.	Uncertain	There may be some PWSs that serve counties and tribal areas. However, if only the county was listed in SDWIS, the EJ analysis does not account for the associated tribal area.
The IEUBK model does not capture very small changes.	Underestimate	The human health effects from changes in lead exposure analysis is based on IEUBK model geometric mean PbB values for each cohort in each CBG under the baseline and the regulatory options. The IEUBK model processes daily intake to two decimal places (µg/day), so some of the change between the baseline and regulatory options is not accounted for by using the model (*i.e.*, IEUBK does not capture very small changes) since the estimated changes in health effects are driven by very small changes across large populations. This aspect of the model contributes to potential underestimation of the lead-related health effects in children in the different subgroups.
EPA's approach to characterizing risks among subgroups did not account for differences in susceptibility or vulnerability among subgroups according to income or race/ethnicity by, for example, using air pollutant concentration-response relationships that account for population race or ethnicity.	Uncertain	This analysis reflects solely the geographical distribution of air quality changes and differences in socioeconomic characteristics of the counties that see projected changes in air quality. People in different subgroup may be more or less susceptible to changes in pollutant exposure.
The spatial resolution of information used in the analysis on changes in air quality limits the degree to which changes in population subgroup exposure can be characterized.	Uncertain	EPA used county-level input data to assess the distribution of changes in air quality and their impacts on different populations. This is a fairly coarse resolution for detecting differences in exposure or risk among population subgroups.

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A Changes to Benefits Methodology since 2019 Proposed Rule Analysis

The table below summarizes the principal methodological changes EPA made to analyses of the benefits of the final rule regulatory options, as compared to the analyses of the 2019 proposed rule (U.S. EPA, 2019a).

Table A-1: Changes to Benefits Analysis Since 2019 Proposed Rule

Benefits Category	Analysis Component [2019 proposed rule analysis value]	Changes to Analysis for regulatory options [2020 rule analysis value]
General inputs and pollutant loads		
Regulatory options analyzed	EPA analyzed the four proposed options (Options, 1, 2, 3, and 4)	EPA conducted new analyses only for Options A, B, and C, and did not re-analyze Option D, which corresponds to proposed Option 1.
Universe of plants, EGUs, and receiving reaches	Analysis includes loadings for only coal-fired units operating as of December 31, 2028.	Analysis includes loadings for all coal-fired units operating as of 2020. The analysis also reflects other updates to the steam electric industry profile through the end of 2019, including the timing of projected retirements and refueling projects and existing treatment technologies. See *Supplemental TDD* for details (U.S. EPA, 2020g).
General pollutant loadings and concentrations	Affected reaches based on immediate receiving reaches and flow paths in medium-resolution NHD.	Updated immediate receiving reaches for selected plants.
	SPARROW modeling of nutrient and sediment concentrations in receiving and downstream reaches based on national SPARROW models and Enhanced River File 1 (E2RF1) stream network.	SPARROW modeling of nutrient and sediment concentrations in receiving and downstream reaches based on the most recent five regional SPARROW models that use the medium-resolution NHD stream network.
	Uses the annual average loadings for analysis period [2021-2047], with pre-technology implementation loads set equal to current loads.	Uses the annual average loadings for two distinct periods during the analysis: 2021-2028 and 2029-2047, with pre-technology implementation loads set equal to current loads and post-retirement or repowering loads set to zero.
Water quality index	Expresses overall water quality changes using a seven-parameter index that includes subindex curve parameters for nutrients and sediment based on the national SPARROW models.	Expresses overall water quality changes using a seven-parameter index that includes subindex curve parameters for nutrients and sediment based on the regional SPARROW models.
Human health benefits from changes in exposure to halogenated disinfection byproducts in drinking water		
Public water systems affected by bromide discharges	Modeled changes in bromide concentrations in source water of public water systems and total trihalomethane concentrations in drinking water.	Modeled changes in bromide concentrations in source water of public water systems.
Public water systems affected by iodine discharges	Not analyzed. Referred to qualitative discussion in *Supplemental EA* (U.S. EPA, 2019j)	Modeled changes in iodine concentrations in source water of public water systems.

Table A-1: Changes to Benefits Analysis Since 2019 Proposed Rule

Benefits Category	Analysis Component [2019 proposed rule analysis value]	Changes to Analysis for regulatory options [2020 rule analysis value]
Lifetime changes in incidence of bladder cancer	Applied lifetime risk model to estimate changes in bladder cancer incidence in population served by public water systems.	Qualitative discussion. EPA received public comments that further evaluation of certain DBPs should be completed and that the analysis at proposal should be subjected to peer review. EPA acknowledges that further study in this area should be conducted, including peer review of the model used at proposal. EPA will continue to evaluate the scientific data on the health impacts of DBPs.
Monetization of changes in incidence of bladder cancer	Mortality valued using VSL (U.S. EPA, 2010a). Morbidity valued based on COI (Greco *et al.*, 2019).	Because EPA did not calculate changes in incidence of bladder cancer, the Agency was unable to monetize this effect.
Non-market benefits from water quality improvements		
WTP for water quality improvements	Meta-regression model	EPA added 14 new studies to the 2015 meta-data and re-estimated the meta-regression model (see *Appendix G* for details). Similar to the 2015 meta-regression, the model includes spatial characteristics of the affected water resources: size of the market, waterbody characteristics (length and flow), availability of substitute sites, and land use type in the adjacent counties. Variables characterizing the availability of substitute sites, size of the market, and land-use were revised based on changes in the universe of receiving reaches and CBGs included in the analysis.
Effects on T&E species	Categorical analysis based on designated critical habitat overlap/proximity to reaches with estimated changes in NRWQC exceedances.	EPA updated the list of species included in the analysis based on the 2020 ECOS online database (U.S. FWS, 2020d). EPA also relied on the habitat range of T&E species in determining whether reaches downstream from steam electric power plant outfalls intersect species habitat (U.S. FWS, 2020b), rather than "critical habitat" as the term is defined in the ESA. EPA included all species categorized as having higher vulnerability to water pollution in its analysis (see Chapter 7 and Appendix H for details). The only exception is species endemic to springs and headwaters.
Air quality-related effects		
Emissions changes	Emissions from changes in electricity generation profile from 2018 and 2019 IPM runs. Energy use-associated emissions based on emission factors estimated using the 2018 and 2019 IPM runs.	Emissions from changes in electricity generation profile from 2020 IPM runs. Energy use-associated emissions were updated to reflect emission factors estimated using the 2020 IPM runs.

Table A-1: Changes to Benefits Analysis Since 2019 Proposed Rule

Benefits Category	**Analysis Component [2019 proposed rule analysis value]**	**Changes to Analysis for regulatory options [2020 rule analysis value]**
Air quality changes	Qualitative discussion.	Used the ACE modeling methodology to estimate changes in air pollutant concentrations.
Monetization	Qualitative discussion.	Used BenMAP-CE model to estimate associated human health benefits.

B WQI Calculation and Regional Subindices

B.1 WQI Calculation

The first step in the implementation of the WQI involves obtaining water quality levels for each parameter, and for each waterbody, under both the baseline conditions and each regulatory option. Some parameter levels are field measurements while others are modeled values.

The second step involves transforming the parameter measurements into subindex values that express water quality conditions on a common scale of 0 to 100. EPA used the subindex transformation curves developed by Dunnette (1979) and Cude (2001) for the Oregon WQI for BOD, DO, and FC. For suspended sediment, TN, and TP concentrations, EPA adapted the approach developed by Cude (2001) to account for the wide range of natural or background nutrient and sediment concentrations that result from variability in geologic and other region-specific conditions, and to reflect the national context of the analysis. Suspended sediment, TN, and TP subindex curves were developed for each Level III ecoregion (Omernik & Griffith, 2014) using pre-compliance (before the implementation of the 2015 rule) SSC and TN and TP concentrations modeled in SPARROW at the medium-resolution NHD reach level.[93] For each of the 84 Level III ecoregions intersected by the NHD reach network, EPA derived the transformation curves by assigning a score of 100 to the 25th percentile of the reach-level SSC level in the ecoregion (*i.e.*, using the 25th percentile as a proxy for "reference" concentrations), and a score of 70 to the median concentration. An exponential equation was then fitted to the two concentration points following the approach used in Cude (2001).

For this analysis, EPA also used a toxics-specific subindex curve based on the number of NRWQC exceedances for toxics in each waterbody. National freshwater chronic NRWQC values are available for arsenic, cadmium, chromium, copper, lead, mercury, nickel, selenium, and zinc. See the *Supplemental EA* for details on the NRWQC (U.S. EPA, 2020f). To develop this subindex curve, EPA used an approach developed by the Canadian Council of Ministers of the Environment (CCME, 2001). The CCME water quality index is based on three attributes of water quality that relate to water quality objectives: scope (number of monitored parameters that exceed water quality standard or toxicological benchmark); frequency (number of individual measurements that do not meet objectives, relative to the total number of measurements for the time period of interest) and amplitude (*i.e.*, amount by which measured values exceed the standards or benchmarks). Following the CCME approach, EPA's toxics subindex considers the number of parameters with exceedances of the relevant water quality criterion. With regards to frequency, EPA modeled long-term annual average concentrations in ambient water, and therefore any exceedance of an NRWQC may indicate that ambient concentrations exceed NRWQC most of the time (assumed to be 100 percent of the time). EPA did not consider amplitude, because if the annual average concentration exceeds the chronic NRWQC then the water is impaired for that constituent and the level of exceedance is of secondary concern. Using this approach, the subindex curve for toxics assigns the lowest subindex score of 0 to waters where exceedances are observed for all nine of the toxics analyzed, and a maximum score of 100 to waters where there are no exceedances. Intermediate values are distributed evenly between 0 and 100.

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[93] The SPARROW model was developed by the USGS for the regional interpretation of water-quality monitoring data. The model relates in-stream water-quality measurements to spatially referenced characteristics of watersheds, including contaminant sources and factors influencing terrestrial and aquatic transport. SPARROW empirically estimates the origin and fate of contaminants in river networks and quantifies uncertainties in model predictions. More information on SPARROW can be found at http://water.usgs.gov/nawqa/sparrow/FAQs/faq.html#1

Table B-1 presents parameter-specific functions used for transforming water quality data into water quality subindices for freshwater waterbodies for the six pollutants with individual subindices. Table B-2 presents the subindex values for toxics. The equation parameters for each of the 84 ecoregion-specific SSC, TN, and TP subindex curves are provided in the next section. The curves include threshold values below or above which the subindex score does not change in response to changes in parameter levels. For example, improving DO levels from 10.5 mg/L to 12 mg/L or from 2 mg/L to 3.3 mg/L would result in no change in the DO subbindex score.

Table B-1: Freshwater Water Quality Subindices

Parameter	Concentrations	Concentration Unit	Subindex
Dissolved Oxygen (DO)			
DO saturation ≤100%			
DO	$DO \le 3.3$	mg/L	10
DO	$3.3 < DO < 10.5$	mg/L	$-80.29+31.88\times DO-1.401\times DO^2$
DO	$DO \ge 10.5$	mg/L	100
100% < DO saturation ≤ 275%			
DO	NA	mg/L	$100 \times \exp((DOsat - 100) \times -1.197\times10^{-2})$
275% < DO saturation			
DO	NA	mg/L	10
Fecal Coliform (FC)			
FC	$FC > 1{,}600$	cfu/100 mL	10
FC	$50 < FC \le 1{,}600$	cfu/100 mL	$98 \times \exp((FC - 50) \times -9.9178\times10^{-4})$
FC	$FC \le 50$	cfu/100 mL	98
Total Nitrogen (TN)[a]			
TN	$TN > TN_{10}$	mg/L	10
TN	$TN_{100} < TN \le TN_{10}$	mg/L	$a \times \exp(TN\times b)$; where a and b are ecoregion-specific values
TN	$TN \le TN_{100}$	mg/L	100
Total Phosphorus (TP)[b]			
TP	$TP > TP_{10}$	mg/L	10
TP	$TP_{100} < TP \le TP_{10}$	mg/L	$a \times \exp(TP\times b)$; where a and b are ecoregion-specific values
TP	$TP \le TP_{100}$	mg/L	100
Suspended Solids[c]			
SSC	$SSC > SSC_{10}$	mg/L	10
SSC	$SSC_{100} < SSC \le SSC_{10}$	mg/L	$a \times \exp(SSC\times b)$; where a and b are ecoregion-specific values
SSC	$SSC \le SSC_{100}$	mg/L	100
Biochemical Oxygen Demand, 5-day (BOD)			
BOD	$BOD > 8$	mg/L	10
BOD	$BOD \le 8$	mg/L	$100 \times \exp(BOD \times -0.1993)$

a. TN10 and TN100 are ecoregion-specific TN concentration values that correspond to subindex scores of 10 and 100, respectively. Use of 10 and 100 for the lower and upper bounds of the WQI subindex score follow the approach in Cude (2001)

b. TP10 and TP100 are ecoregion-specific TP concentration values that correspond to subindex scores of 10 and 100, respectively. Use of 10 and 100 for the lower and upper bounds of the WQI subindex score follow the approach in Cude (2001)

c. SSC10 and SSC100 are ecoregion-specific SSC concentration values that correspond to subindex scores of 10 and 100, respectively. Use of 10 and 100 for the lower and upper bounds of the WQI subindex score follow the approach in Cude (2001)

Source: EPA analysis, 2020, based on methodology in Cude (2001).

Table B-2: Freshwater Water Quality Subindex for Toxics

Number of Toxics with NRWQC Exceedances	Subindex
0	100.0
1	88.9
2	77.8
3	66.7
4	55.6
5	44.4
6	33.3
7	22.2
8	11.1
9	0.0

The final step in implementing the WQI involves combining the individual parameter subindices into a single WQI value that reflects the overall water quality across the parameters. EPA calculated the overall WQI for a given reach using a geometric mean function and assigned all WQ parameters an equal weight of 0.143 (1/7th of the overall score). Unweighted scores for individual metrics of a WQI have previously been used in Cude (2001), CCME, 2001, and Carruthers and Wazniak (2003).

Equation B-1 presents EPA's calculation of the overall WQI score.

Equation B-1.

$$WQI_r = \prod_{i=1}^{n} Q_i^{Wi}$$

WQI_r = the multiplicative water quality index (from 0 to 100) for reach *r*

Q_i = the water quality subindex measure for parameter *i*

W_i = the weight of the *i*-th parameter (0.143)

n = the number of parameters (*i.e.*, seven)

B.2 Regional Subindices

The following tables provide the ecoregion-specific parameters used in estimating the suspended solids, TN, or TP water quality subindex, as follows:

- If [WQ Parameter] ≤ WQ Parameter 100 Subindex = 100
- If WQ Parameter 100 < [WQ Parameter] ≤ WQ Parameter 10 Subindex = a exp(b [WQ Parameter])
- If [WQ Parameter] > WQ Parameter 10 Subindex = 10

Where [WQ Parameter] is the measured concentration of either suspended solids, TN, or TP and WQ Parameter $_{10}$, WQ Parameter $_{100}$, a, and b are specified in Table B-3 for suspended solids, Table B-4 for TN, and Table B-5 for TP.

Table B-3: Suspended Solids Subindex Curve Parameters, by Ecoregion

ID	Ecoregion Name	a	b	SSC_{100}	SSC_{10}
ECOL3_01	Coast Range	140.44	-0.0069	49.5	385.0
ECOL3_02	Strait of Georgia/Puget Lowland	131.95	-0.0044	62.5	581.9
ECOL3_03	Willamette Valley	131.91	-0.0046	59.8	556.9
ECOL3_04	Cascades	108.63	-0.0080	10.4	299.7
ECOL3_05	Sierra Nevada	109.47	-0.0108	8.3	220.7
ECOL3_06	California Coastal Sage, Chaparral, and Oak Woodlands	117.59	-0.0042	38.6	587.6
ECOL3_07	Central California Valley	105.23	-0.0012	42.0	1,940.7
ECOL3_08	Southern and Baja California Pine-Oak Mountains	122.49	-0.0062	32.8	404.8
ECOL3_09	Eastern Cascades Slopes and Foothills	110.36	-0.0053	18.6	453.5
ECOL3_10	Columbia Plateau	105.57	-0.0006	88.8	3,858.9
ECOL3_11	Blue Mountains	118.33	-0.0026	64.2	943.1
ECOL3_12	Snake River Plain	105.49	-0.0012	45.1	1,988.9
ECOL3_13	Central Basin and Range	101.85	-0.0008	22.9	2,901.7
ECOL3_14	Mojave Basin and Range	100.33	-0.0012	2.9	1,999.7
ECOL3_15	Columbia Mountains/Northern Rockies	154.23	-0.0085	50.9	321.4
ECOL3_16	Idaho Batholith	149.46	-0.0111	36.0	242.6
ECOL3_17	Middle Rockies	102.71	-0.0057	4.7	411.9
ECOL3_18	Wyoming Basin	102.05	-0.0005	41.8	4,792.9
ECOL3_19	Wasatch and Uinta Mountains	103.18	-0.0025	12.5	929.9
ECOL3_20	Colorado Plateaus	101.57	-0.0001	111.8	16,595.3
ECOL3_21	Southern Rockies	102.90	-0.0033	8.7	712.1
ECOL3_22	Arizona/New Mexico Plateau	100.30	-0.0001	31.6	24,144.6
ECOL3_23	Arizona/New Mexico Mountains	100.62	-0.0009	6.8	2,562.6
ECOL3_24	Chihuahuan Desert	101.79	-0.0014	12.8	1,671.6
ECOL3_25	High Plains	102.70	-0.0004	66.5	5,806.3
ECOL3_26	Southwestern Tablelands	103.35	-0.0004	74.0	5,239.0
ECOL3_27	Central Great Plains	103.49	-0.0004	94.9	6,462.6
ECOL3_28	Flint Hills	111.64	-0.0012	90.3	1,979.5
ECOL3_29	Cross Timbers	106.31	-0.0017	36.9	1,425.3
ECOL3_30	Edwards Plateau	106.83	-0.0070	9.4	336.3
ECOL3_31	Southern Texas Plains/Interior Plains and Hills with Xerophytic Shrub and Oak Forest	100.74	-0.0008	8.7	2,731.7
ECOL3_32	Texas Blackland Prairies	110.38	-0.0011	91.6	2,226.9
ECOL3_33	East Central Texas Plains	106.96	-0.0008	84.8	2,987.0
ECOL3_34	Western Gulf Coastal Plain	103.78	-0.0012	31.1	1,964.6
ECOL3_35	South Central Plains	117.84	-0.0050	32.7	491.8
ECOL3_36	Ouachita Mountains	175.85	-0.0157	36.0	182.8
ECOL3_37	Arkansas Valley	124.25	-0.0060	35.9	416.7
ECOL3_38	Boston Mountains	240.61	-0.0252	34.8	126.1
ECOL3_39	Ozark Highlands	137.77	-0.0034	95.1	778.1
ECOL3_40	Central Irregular Plains	116.98	-0.0008	193.2	3,030.6
ECOL3_41	Canadian Rockies	102.38	-0.0064	3.7	364.9
ECOL3_42	Northwestern Glaciated Plains	101.25	-0.0002	49.9	9,287.6
ECOL3_43	Northwestern Great Plains	102.30	-0.0004	50.8	5,192.4
ECOL3_44	Nebraska Sand Hills	108.78	-0.0073	11.5	327.0
ECOL3_45	Piedmont	123.28	-0.0043	48.5	582.1

Table B-3: Suspended Solids Subindex Curve Parameters, by Ecoregion

ID	Ecoregion Name	a	b	SSC_{100}	SSC_{10}
ECOL3_46	Aspen Parkland/Northern Glaciated Plains	106.80	-0.0005	121.8	4,382.1
ECOL3_47	Western Corn Belt Plains	113.45	-0.0008	150.6	2,899.9
ECOL3_48	Lake Manitoba and Lake Agassiz Plain	106.32	-0.0009	66.3	2,558.1
ECOL3_49	Northern Minnesota Wetlands	104.69	-0.0047	9.7	498.9
ECOL3_50	Northern Lakes and Forests	101.64	-0.0302	0.5	76.8
ECOL3_51	North Central Hardwood Forests	101.18	-0.0063	1.9	367.1
ECOL3_52	Driftless Area	113.90	-0.0025	51.8	968.9
ECOL3_53	Southeastern Wisconsin Till Plains	107.87	-0.0015	50.0	1,569.9
ECOL3_54	Central Corn Belt Plains	126.49	-0.0018	132.9	1,434.9
ECOL3_55	Eastern Corn Belt Plains	137.96	-0.0013	238.5	1,945.4
ECOL3_56	Southern Michigan/Northern Indiana Drift Plains	104.69	-0.0049	9.4	482.9
ECOL3_57	Huron/Erie Lake Plains	110.27	-0.0022	45.0	1,105.5
ECOL3_58	Northern Appalachian and Atlantic Maritime Highlands	105.30	-0.0220	2.3	106.9
ECOL3_59	Northeastern Coastal Zone	109.98	-0.0213	4.5	112.6
ECOL3_60	Northern Allegheny Plateau	112.39	-0.0059	19.7	408.7
ECOL3_61	Erie Drift Plain	115.53	-0.0021	69.3	1,174.2
ECOL3_62	North Central Appalachians	122.90	-0.0192	10.7	130.6
ECOL3_63	Middle Atlantic Coastal Plain	105.17	-0.0077	6.6	306.4
ECOL3_64	Northern Piedmont	124.31	-0.0048	45.0	521.0
ECOL3_65	Southeastern Plains	118.94	-0.0065	26.8	382.9
ECOL3_66	Blue Ridge	108.09	-0.0080	9.7	297.3
ECOL3_67	Ridge and Valley	115.89	-0.0049	30.1	500.8
ECOL3_68	Southwestern Appalachians	124.64	-0.0070	31.5	360.3
ECOL3_69	Central Appalachians	121.03	-0.0113	16.9	220.7
ECOL3_70	Western Allegheny Plateau	120.20	-0.0030	61.8	835.8
ECOL3_71	Interior Plateau	137.46	-0.0038	84.8	698.8
ECOL3_72	Interior River Valleys and Hills	116.26	-0.0011	135.9	2,212.1
ECOL3_73	Mississippi Alluvial Plain	105.34	-0.0008	63.4	2,866.1
ECOL3_74	Mississippi Valley Loess Plains	115.94	-0.0026	56.1	930.1
ECOL3_75	Southern Coastal Plain	100.33	-0.0113	0.3	204.7
ECOL3_77	North Cascades	140.30	-0.0083	40.9	318.7
ECOL3_78	Klamath Mountains	142.69	-0.0124	28.6	213.7
ECOL3_79	Madrean Archipelago	100.41	-0.0021	1.9	1,078.2
ECOL3_80	Northern Basin and Range	102.69	-0.0010	26.5	2,319.2
ECOL3_81	Sonoran Desert	100.09	-0.0021	0.4	1,072.2
ECOL3_82	Acadian Plains and Hills	110.65	-0.0302	3.4	79.7
ECOL3_83	Eastern Great Lakes Lowlands	103.55	-0.0031	11.4	764.8
ECOL3_84	Atlantic Coastal Pine Barrens	105.25	-0.0173	3.0	135.8
ECOL3_85	California Coastal Sage, Chaparral, and Oak Woodlands	104.56	-0.0005	95.8	5,039.6

Table B-4: TN Subindex Curve Parameters, by Ecoregion

ID	Ecoregion Name	a	b	TN_{100}	TN_{10}
ECOL3_01	Coast Range	117.12	-1.576	0.10	1.56
ECOL3_02	Strait of Georgia/Puget Lowland	115.02	-0.618	0.23	3.95

Table B-4: TN Subindex Curve Parameters, by Ecoregion

ID	Ecoregion Name	a	b	TN_{100}	TN_{10}
ECOL3_03	Willamette Valley	124.45	-0.626	0.35	4.03
ECOL3_04	Cascades	140.20	-4.890	0.07	0.54
ECOL3_05	Sierra Nevada	147.87	-5.172	0.08	0.52
ECOL3_06	California Coastal Sage, Chaparral, and Oak Woodlands	115.62	-0.753	0.19	3.25
ECOL3_07	Central California Valley	106.36	-0.182	0.34	13.02
ECOL3_08	Southern and Baja California Pine-Oak Mountains	132.91	-1.449	0.20	1.79
ECOL3_09	Eastern Cascades Slopes and Foothills	124.23	-2.589	0.08	0.97
ECOL3_10	Columbia Plateau	107.54	-0.213	0.34	11.13
ECOL3_11	Blue Mountains	128.88	-1.825	0.14	1.40
ECOL3_12	Snake River Plain	112.05	-0.421	0.27	5.74
ECOL3_13	Central Basin and Range	142.81	-1.582	0.23	1.68
ECOL3_14	Mojave Basin and Range	168.00	-1.527	0.34	1.85
ECOL3_15	Columbia Mountains/Northern Rockies	162.78	-6.219	0.08	0.45
ECOL3_16	Idaho Batholith	175.32	-6.599	0.09	0.43
ECOL3_17	Middle Rockies	125.63	-1.555	0.15	1.63
ECOL3_18	Wyoming Basin	133.37	-0.991	0.29	2.61
ECOL3_19	Wasatch and Uinta Mountains	182.10	-3.323	0.18	0.87
ECOL3_20	Colorado Plateaus	139.56	-1.074	0.31	2.45
ECOL3_21	Southern Rockies	125.73	-1.312	0.17	1.93
ECOL3_22	Arizona/New Mexico Plateau	164.67	-1.394	0.36	2.01
ECOL3_23	Arizona/New Mexico Mountains	196.35	-2.556	0.26	1.16
ECOL3_24	Chihuahuan Desert	178.59	-1.966	0.29	1.47
ECOL3_25	High Plains	128.76	-0.238	1.06	10.73
ECOL3_26	Southwestern Tablelands	117.79	-0.402	0.41	6.14
ECOL3_27	Central Great Plains	122.53	-0.161	1.26	15.57
ECOL3_28	Flint Hills	172.99	-0.487	1.13	5.85
ECOL3_29	Cross Timbers	127.67	-0.539	0.45	4.73
ECOL3_30	Edwards Plateau	275.43	-2.830	0.36	1.17
ECOL3_31	Southern Texas Plains/Interior Plains and Hills with Xerophytic Shrub and Oak Forest	134.52	-1.349	0.22	1.93
ECOL3_32	Texas Blackland Prairies	140.22	-0.528	0.64	5.00
ECOL3_33	East Central Texas Plains	147.35	-0.877	0.44	3.07
ECOL3_34	Western Gulf Coastal Plain	108.99	-0.486	0.18	4.91
ECOL3_35	South Central Plains	166.55	-1.506	0.34	1.87
ECOL3_36	Ouachita Mountains	549.75	-3.223	0.53	1.24
ECOL3_37	Arkansas Valley	177.73	-0.855	0.67	3.37
ECOL3_38	Boston Mountains	280.85	-1.715	0.60	1.94
ECOL3_39	Ozark Highlands	163.12	-0.707	0.69	3.95
ECOL3_40	Central Irregular Plains	180.12	-0.386	1.53	7.50
ECOL3_41	Canadian Rockies	168.86	-4.873	0.11	0.58
ECOL3_42	Northwestern Glaciated Plains	112.01	-0.198	0.57	12.19
ECOL3_43	Northwestern Great Plains	128.64	-0.450	0.56	5.67
ECOL3_44	Nebraska Sand Hills	130.07	-0.440	0.60	5.83
ECOL3_45	Piedmont	184.09	-1.008	0.61	2.89
ECOL3_46	Aspen Parkland/Northern Glaciated Plains	131.56	-0.109	2.52	23.65
ECOL3_47	Western Corn Belt Plains	135.26	-0.101	3.00	25.87

Table B-4: TN Subindex Curve Parameters, by Ecoregion

ID	Ecoregion Name	a	b	TN_{100}	TN_{10}
ECOL3_48	Lake Manitoba and Lake Agassiz Plain	121.75	-0.137	1.44	18.24
ECOL3_49	Northern Minnesota Wetlands	223.00	-1.380	0.58	2.25
ECOL3_50	Northern Lakes and Forests	146.53	-1.166	0.33	2.30
ECOL3_51	North Central Hardwood Forests	119.82	-0.244	0.74	10.17
ECOL3_52	Driftless Area	143.37	-0.237	1.52	11.25
ECOL3_53	Southeastern Wisconsin Till Plains	130.76	-0.155	1.73	16.60
ECOL3_54	Central Corn Belt Plains	141.14	-0.110	3.14	24.13
ECOL3_55	Eastern Corn Belt Plains	122.49	-0.109	1.86	23.00
ECOL3_56	Southern Michigan/Northern Indiana Drift Plains	129.61	-0.236	1.10	10.86
ECOL3_57	Huron/Erie Lake Plains	118.83	-0.103	1.68	24.11
ECOL3_58	Northern Appalachian and Atlantic Maritime Highlands	180.97	-2.805	0.21	1.03
ECOL3_59	Northeastern Coastal Zone	139.63	-1.023	0.33	2.58
ECOL3_60	Northern Allegheny Plateau	135.73	-0.742	0.41	3.52
ECOL3_61	Erie Drift Plain	174.63	-0.463	1.20	6.18
ECOL3_62	North Central Appalachians	173.28	-1.578	0.35	1.81
ECOL3_63	Middle Atlantic Coastal Plain	117.16	-0.371	0.43	6.63
ECOL3_64	Northern Piedmont	127.21	-0.327	0.74	7.78
ECOL3_65	Southeastern Plains	192.15	-1.201	0.54	2.46
ECOL3_66	Blue Ridge	276.75	-1.954	0.52	1.70
ECOL3_67	Ridge and Valley	141.88	-0.720	0.49	3.69
ECOL3_68	Southwestern Appalachians	256.93	-1.490	0.63	2.18
ECOL3_69	Central Appalachians	675.15	-3.064	0.62	1.37
ECOL3_70	Western Allegheny Plateau	340.07	-1.467	0.83	2.40
ECOL3_71	Interior Plateau	152.97	-0.594	0.72	4.59
ECOL3_72	Interior River Valleys and Hills	123.32	-0.196	1.07	12.84
ECOL3_73	Mississippi Alluvial Plain	119.35	-0.337	0.53	7.37
ECOL3_74	Mississippi Valley Loess Plains	161.09	-1.056	0.45	2.63
ECOL3_75	Southern Coastal Plain	150.19	-0.711	0.57	3.81
ECOL3_77	North Cascades	161.05	-5.800	0.08	0.48
ECOL3_78	Klamath Mountains	144.12	-5.333	0.07	0.50
ECOL3_79	Madrean Archipelago	184.29	-2.163	0.28	1.35
ECOL3_80	Northern Basin and Range	118.17	-1.049	0.16	2.36
ECOL3_81	Sonoran Desert	134.26	-1.398	0.21	1.86
ECOL3_82	Acadian Plains and Hills	153.19	-3.186	0.13	0.86
ECOL3_83	Eastern Great Lakes Lowlands	124.57	-0.396	0.55	6.37
ECOL3_84	Atlantic Coastal Pine Barrens	113.96	-0.612	0.21	3.97
ECOL3_85	California Coastal Sage, Chaparral, and Oak Woodlands	108.05	-0.149	0.52	16.00

Table B-5: TP Subindex Curve Parameters, by Ecoregion

ID	Ecoregion Name	a	b	TP_{100}	TP_{10}
ECOL3_01	Coast Range	120.62	-11.18	0.017	0.223
ECOL3_02	Strait of Georgia/Puget Lowland	116.41	-7.23	0.021	0.340
ECOL3_03	Willamette Valley	122.02	-4.53	0.044	0.552
ECOL3_04	Cascades	127.84	-19.74	0.012	0.129

Table B-5: TP Subindex Curve Parameters, by Ecoregion

ID	Ecoregion Name	a	b	TP_{100}	TP_{10}
ECOL3_05	Sierra Nevada	120.03	-31.12	0.006	0.080
ECOL3_06	California Coastal Sage, Chaparral, and Oak Woodlands	111.64	-5.08	0.022	0.475
ECOL3_07	Central California Valley	109.69	-2.16	0.043	1.110
ECOL3_08	Southern and Baja California Pine-Oak Mountains	109.66	-5.64	0.016	0.424
ECOL3_09	Eastern Cascades Slopes and Foothills	114.91	-8.82	0.016	0.277
ECOL3_10	Columbia Plateau	106.54	-0.98	0.064	2.409
ECOL3_11	Blue Mountains	112.26	-4.21	0.027	0.575
ECOL3_12	Snake River Plain	104.86	-1.19	0.040	1.975
ECOL3_13	Central Basin and Range	106.44	-8.32	0.007	0.284
ECOL3_14	Mojave Basin and Range	102.55	-6.82	0.004	0.341
ECOL3_15	Columbia Mountains/Northern Rockies	119.55	-26.30	0.007	0.094
ECOL3_16	Idaho Batholith	124.76	-11.69	0.019	0.216
ECOL3_17	Middle Rockies	107.73	-5.56	0.013	0.427
ECOL3_18	Wyoming Basin	106.78	-1.31	0.050	1.810
ECOL3_19	Wasatch and Uinta Mountains	109.62	-15.21	0.006	0.157
ECOL3_20	Colorado Plateaus	107.19	-4.62	0.015	0.514
ECOL3_21	Southern Rockies	110.45	-6.82	0.015	0.352
ECOL3_22	Arizona/New Mexico Plateau	103.18	-4.06	0.008	0.575
ECOL3_23	Arizona/New Mexico Mountains	104.60	-13.34	0.003	0.176
ECOL3_24	Chihuahuan Desert	109.07	-12.20	0.007	0.196
ECOL3_25	High Plains	113.62	-0.57	0.225	4.282
ECOL3_26	Southwestern Tablelands	107.60	-1.24	0.059	1.913
ECOL3_27	Central Great Plains	112.74	-0.48	0.250	5.055
ECOL3_28	Flint Hills	129.43	-1.39	0.185	1.837
ECOL3_29	Cross Timbers	108.32	-3.40	0.023	0.700
ECOL3_30	Edwards Plateau	110.37	-26.58	0.004	0.090
ECOL3_31	Southern Texas Plains/Interior Plains and Hills with Xerophytic Shrub and Oak Forest	102.67	-7.15	0.004	0.326
ECOL3_32	Texas Blackland Prairies	112.92	-1.99	0.061	1.221
ECOL3_33	East Central Texas Plains	106.42	-2.53	0.025	0.934
ECOL3_34	Western Gulf Coastal Plain	100.87	-1.57	0.006	1.469
ECOL3_35	South Central Plains	120.39	-7.58	0.024	0.328
ECOL3_36	Ouachita Mountains	133.54	-15.66	0.018	0.165
ECOL3_37	Arkansas Valley	112.48	-2.72	0.043	0.891
ECOL3_38	Boston Mountains	131.47	-9.61	0.028	0.268
ECOL3_39	Ozark Highlands	114.84	-3.37	0.041	0.724
ECOL3_40	Central Irregular Plains	164.67	-2.20	0.227	1.274
ECOL3_41	Canadian Rockies	134.76	-33.85	0.009	0.077
ECOL3_42	Northwestern Glaciated Plains	110.26	-0.62	0.158	3.877
ECOL3_43	Northwestern Great Plains	117.40	-1.13	0.142	2.186
ECOL3_44	Nebraska Sand Hills	105.59	-1.69	0.032	1.392
ECOL3_45	Piedmont	132.98	-5.22	0.055	0.496
ECOL3_46	Aspen Parkland/Northern Glaciated Plains	128.82	-0.76	0.332	3.353
ECOL3_47	Western Corn Belt Plains	172.45	-1.54	0.355	1.854
ECOL3_48	Lake Manitoba and Lake Agassiz Plain	112.93	-0.92	0.131	2.622
ECOL3_49	Northern Minnesota Wetlands	120.81	-12.32	0.015	0.202

Table B-5: TP Subindex Curve Parameters, by Ecoregion

ID	Ecoregion Name	a	b	TP_{100}	TP_{10}
ECOL3_50	Northern Lakes and Forests	118.45	-14.48	0.012	0.171
ECOL3_51	North Central Hardwood Forests	111.56	-2.39	0.046	1.008
ECOL3_52	Driftless Area	139.72	-2.09	0.160	1.263
ECOL3_53	Southeastern Wisconsin Till Plains	132.83	-1.83	0.155	1.411
ECOL3_54	Central Corn Belt Plains	178.81	-2.30	0.253	1.255
ECOL3_55	Eastern Corn Belt Plains	186.94	-2.86	0.219	1.025
ECOL3_56	Southern Michigan/Northern Indiana Drift Plains	130.88	-3.90	0.069	0.659
ECOL3_57	Huron/Erie Lake Plains	142.40	-3.19	0.111	0.832
ECOL3_58	Northern Appalachian and Atlantic Maritime Highlands	132.90	-30.01	0.009	0.086
ECOL3_59	Northeastern Coastal Zone	125.36	-13.84	0.016	0.183
ECOL3_60	Northern Allegheny Plateau	126.26	-9.88	0.024	0.257
ECOL3_61	Erie Drift Plain	134.57	-3.24	0.092	0.803
ECOL3_62	North Central Appalachians	148.98	-21.89	0.018	0.123
ECOL3_63	Middle Atlantic Coastal Plain	112.32	-4.26	0.027	0.568
ECOL3_64	Northern Piedmont	141.23	-5.01	0.069	0.528
ECOL3_65	Southeastern Plains	130.40	-7.65	0.035	0.336
ECOL3_66	Blue Ridge	117.13	-8.26	0.019	0.298
ECOL3_67	Ridge and Valley	113.75	-5.34	0.024	0.455
ECOL3_68	Southwestern Appalachians	127.64	-7.37	0.033	0.345
ECOL3_69	Central Appalachians	141.58	-19.20	0.018	0.138
ECOL3_70	Western Allegheny Plateau	154.57	-6.77	0.064	0.404
ECOL3_71	Interior Plateau	119.63	-2.12	0.085	1.172
ECOL3_72	Interior River Valleys and Hills	134.24	-1.63	0.181	1.595
ECOL3_73	Mississippi Alluvial Plain	102.40	-1.04	0.023	2.229
ECOL3_74	Mississippi Valley Loess Plains	115.53	-2.27	0.064	1.078
ECOL3_75	Southern Coastal Plain	113.24	-6.14	0.020	0.395
ECOL3_77	North Cascades	118.69	-17.30	0.010	0.143
ECOL3_78	Klamath Mountains	117.21	-28.37	0.006	0.087
ECOL3_79	Madrean Archipelago	104.02	-18.29	0.002	0.128
ECOL3_80	Northern Basin and Range	103.35	-2.23	0.015	1.048
ECOL3_81	Sonoran Desert	101.23	-8.38	0.001	0.276
ECOL3_82	Acadian Plains and Hills	113.37	-25.58	0.005	0.095
ECOL3_83	Eastern Great Lakes Lowlands	114.01	-3.62	0.036	0.673
ECOL3_84	Atlantic Coastal Pine Barrens	109.88	-11.65	0.008	0.206
ECOL3_85	California Coastal Sage, Chaparral, and Oak Woodlands	104.34	-1.37	0.031	1.717

C Derivation of Ambient Water and Fish Tissue Concentrations in Receiving and Downstream Reaches

This appendix describes the methodology EPA used to estimate water and fish tissue concentrations under the baseline and each of the regulatory options. The concentrations are used as inputs to estimate the water quality changes and human health benefits of the regulatory options. Specifically, EPA used ambient water toxics concentrations to derive fish tissue concentrations used to analyze human health effects from consuming self-caught fish (see Chapter 5) and to analyze non-use benefits of water quality changes (see Chapter 6). Nutrient and suspended solids concentrations are used to support analysis of non-use benefits from water quality changes (see Chapter 6).

The overall modeling methodology builds on data and methods described in the *Supplemental EA* and *Supplemental TDD* for the regulatory options (U.S. EPA, 2020f, 2020g). The following sections discuss calculations of the toxics concentrations in ambient water and fish tissue and nutrient and sediment concentrations in ambient water.

C.1 Toxics

Estimating Water Concentrations in each Reach

EPA first estimated the baseline and regulatory option toxics concentrations in reaches receiving steam electric power plant discharges and downstream reaches.

The D-FATE model (see Chapter 3) was used to estimate water concentrations. The model tracks the fate and transport of discharged pollutants through a reach network defined based on the medium resolution NHD.[94] The hydrography network represented in the D-FATE model consists of 11,369 reaches within 300 km of a steam electric power plant, 10,454 of which are estimated to be potentially fishable.[95]

The analysis involved the following key steps for the baseline and each of the regulatory options:

- **Summing plant-level loadings to the receiving reach**. EPA summed the estimated plant-level annual average loads for each unique reach receiving plant discharges from steam electric power plants in the baseline and under the regulatory options. For a description of the approach EPA used to identify the receiving waterbodies, see U.S. EPA, 2020f.

- **Performing dilution and transport calculations**. The D-FATE model calculates the concentration of the pollutant in a given reach based on the total mass transported to the reach from upstream sources and the EROM flows for each reach from NHDPlus v2. In the model, a plant is assumed to

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[94] The USGS's National Hydrology Dataset (NHD) defines a reach as a continuous piece of surface water with similar hydrologic characteristics. In the NHD each reach is assigned a reach code; a reach may be composed of a single feature, like a lake or isolated stream, but reaches may also be composed of a number of contiguous features. Each reach code occurs only once throughout the nation and once assigned a reach code is permanently associated with its reach. If the reach is deleted, its reach code is retired.

[95] Reaches represented in the D-FATE model are those estimated to be potentially fishable based on type and physical characteristics. Because the D-FATE model calculates the movement of a chemical release downstream using flow data, reaches must have at least one downstream or upstream connecting reach and have a non-negative flow and velocity. The D-FATE model does not calculate concentrations for certain types of reaches, such as coastlines, treatment reservoirs, and bays; the downstream path of any chemical is assumed to stop if one of these types of reach is encountered. Additionally, some types of reaches are excluded from the set of fishable reaches, such as those designated as having Strahler Stream Order 1 in the NHDPlus, because they do not have the flow rates and species diversity to support trophic level 3 and 4 species.

release its annual load at a constant rate throughout the year. Each source-pollutant release is tracked throughout the NHD reach network until the terminal reach.[96]

- **Specifying concentrations in the water quality model**. The D-FATE model includes background data on estimated annual average pollutant concentrations to surface waters from facilities that reported to the TRI in 2016. EPA added background concentrations where available to concentration estimates from steam electric power plant dischargers.

EPA used the approach above to estimate annual average concentrations of ten toxics: arsenic, cadmium, hexavalent chromium, copper, lead, mercury, nickel, selenium, thallium, and zinc.

Estimating Fish Tissue Concentrations in each Reach

To support analysis of the human health benefits associated with water quality improvements (see Chapter 4), EPA estimated concentrations of arsenic, lead, and mercury in fish tissue based on the D-FATE model outputs discussed above.

The methodology follows the same general approach described in the *Supplemental EA* for estimating fish tissue concentrations for receiving reaches (U.S. EPA, 2020f), but applies the calculations to the larger set of reaches modeled using D-FATE, which include not only the receiving reaches analyzed in the EA, but also downstream reaches. Further, the calculations use D-FATE-estimated concentrations as inputs, which account not only for the steam electric power plant discharges, but also other major dischargers that report to TRI. The methodology follows the same general approach described in the *Supplemental EA* for estimating fish tissue concentrations for receiving reaches (U.S. EPA, 2020f), but applies the calculations to the larger set of reaches modeled using D-FATE, which include not only the immediate receiving reaches analyzed in the EA, but also downstream reaches. Further, the calculations use D-FATE-estimated concentrations as inputs, which account not only for the steam electric power plant discharges, but also other major dischargers that report to TRI.

The analysis involved the following key steps for the baseline and each of the regulatory options:

1. **Obtaining the relationship between water concentrations and fish tissue concentrations**. EPA used the results of the Immediate Receiving Water (IRW) model (see *Supplemental EA*, U.S. EPA, 2020f) to parameterize the linear relationship between water concentrations in receiving reaches and composite fish tissue concentrations (representative of trophic levels 3 and 4 fish consumed) in these same reaches for each of the three toxics.

2. **Calculating fish tissue data for affected reaches**. For reaches for which the D-FATE model provides non-zero water concentrations (*i.e.*, reaches affected by steam electric power plants or other TRI dischargers), EPA used the relationship obtained in Step 1 to calculate a preliminary fish tissue concentration for each pollutant.

3. **Imputing the fish tissue concentrations for all other modeled reaches**. For reaches for which the D-FATE model calculates water concentrations, EPA added background fish tissue concentrations based on the 10th percentile of the distribution of reported concentrations in fish

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[96] For some analyses, EPA limits the scope of reaches to 300 km (186 miles) downstream from steam electric power plant outfalls.

tissue samples in the National Listing Fish Advisory (NLFA) data[97] (see Table C-1). EPA found that the distribution of these samples was consistent with values reported in Wathen *et al.* (2015) and used the 10th percentile as representative of background levels in "clean" reaches not affected by point source discharges.

4. **Validating and adjusting the fish tissue concentrations based on empirical data, if needed**. EPA then applied the same method used to validate and adjust estimated fish tissue data in the IRW model to ensure that the fish tissue concentrations calculated based on the D-FATE model outputs are reasonable when compared to measured data. The approach involves applying order-of-magnitude adjustments in cases where the preliminary concentrations are greater than empirical measurements for a given reach or geographic area by an order of magnitude or more. The *Supplemental EA* describes the methodology in greater detail (U.S. EPA, 2020f).

The analysis provides background toxic-specific composite fish fillet concentrations for each reach modeled in the D-FATE model. Total fish tissue concentrations (D-FATE modeled concentrations plus background concentrations) are summarized in Table C-2.

Table C-1: Background Fish Tissue Concentrations, based on 10th percentile

Parameter	Pollutant Concentration (mg/kg)
As	0.039
Hg	0.058
Pb	0.039

Source: U.S. EPA Analysis, 2020

Table C-2: Imputed and Validated Fish Tissue Concentrations by Regulatory Option

Regulatory Option	Fish Fillet Concentration (mg/kg)								
	Arsenic			Lead			Mercury		
	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean
Period 1									
Baseline	0.0390	0.2174	0.0391	0.0390	2.3318	0.0400	0.0580	7.2341	0.0669
Option A	0.0390	0.3363	0.0391	0.0390	3.8604	0.0406	0.0580	12.0181	0.0755
Option B	0.0390	0.3363	0.0391	0.0390	3.8604	0.0406	0.0580	12.0181	0.0743
Option C	0.0390	0.3363	0.0391	0.0390	3.8604	0.0406	0.0580	12.0181	0.0760
Period 2									
Baseline	0.0390	0.0469	0.0390	0.0390	0.0918	0.0390	0.0580	1.6952	0.0590
Option A	0.0390	0.0471	0.0390	0.0390	0.0942	0.0390	0.0580	1.7436	0.0593
Option B	0.0390	0.0471	0.0390	0.0390	0.0942	0.0390	0.0580	1.7436	0.0592
Option C	0.0390	0.0399	0.0390	0.0390	0.0503	0.0390	0.0580	0.4824	0.0583

Source: U.S. EPA Analysis, 2020.

C.2 Nutrients and Suspended Sediment

EPA used the USGS's regional SPARROW models to estimate nutrient and sediment concentrations in receiving and downstream reaches. The regional models used for this analysis are the five regional models developed for the Pacific, Southwest, Midwest, Southeast, and Northeast regions for flow, total nitrogen

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[97] See https://fishadvisoryonline.epa.gov/general.aspx.

(TN), total phosphorus (TP), and suspended sediment (Ator, 2019; Hoos & Roland Ii, 2019; Robertson & Saad, 2019; Wise, 2019; Wise *et al.*, 2019). EPA adjusted the models to include a variable for steam electric discharges using the following steps:

- **Specifying a source load parameter for steam electric discharges.** The regional SPARROW models do not include an explicit explanatory variable for point sources related to industrial dischargers (non publicly owned treatment works). EPA recalibrated the regional models by adding a variable for steam electric loadings, initially setting all loadings for this parameter equal to zero, assigning this new variable a calibration coefficient value of 1, and specifying zero land-to-water delivery effects associated with this new variable.
- **Appending steam electric TN, TP, and TSS loadings to regional input data.** Once the regional SPARROW models were recalibrated to include the steam electric loadings variable, EPA added the steam electric TN, TP, and TSS[98] loadings to the model input data and ran each regional model for each pollutant to obtain catchment-level TN, TP, and SSC predictions.

For Periods 1 and 2, the SPARROW models output predicted annual average baseline and regulatory option concentrations in each reach. EPA compared the baseline predictions to the predictions obtained for each of the regulatory options to estimate changes in concentrations.

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[98] TSS loadings are converted to SSC values at this step by using location-specific relationships built into the SPARROW regional models.

D Georeferencing Surface Water Intakes to the Medium-resolution Reach Network

For the 2019 proposal analysis, EPA used the following steps to assign PWS surface water intakes to waters represented in the medium-resolution NHD Plus version 2 dataset and identify those intakes potentially affected by steam electric power plant discharges.

1. Identify the closest (simple cartesian distance) medium-resolution NHD feature (including Flowline, Area, and Waterbody) to each PWS intake.
2. If the closest feature to a given intake was an NHD Flowline, reference the intake to this Flowline.
3. If the closest feature to a given intake was an NHD Area or Waterbody, consider the Flowlines contained within or intersected by the Area/Waterbody.
    a. If any of the Flowlines associated with the Area/Waterbody were on the flowpath downstream from a steam electric power plant, select the Flowline within this set and closest to the intake.
    b. If none of the Flowlines were on the flowpath downstream from a steam electric power plant, select the Flowline closest to the intake.
    c. If there were no Flowlines associated with the Area/Waterbody, select the closest Flowline.

EPA then compared the set of Flowline COMIDs identified in steps 2 and 3 to NHD COMIDs in the downstream flowpath of steam electric power plant discharges. COMIDs that georeferenced directly to the downstream flowpath received a "Category 1" designation. Intakes that were georeferenced to COMIDs within 10 km of the downstream flowpath received a "Category 2" designation. EPA included all intakes within 10 km of the discharge flow path to account for cases where georeferencing did not select the correct COMID based on uncertainty in the flow direction or stream network connectivity. For example, if a PWS intake was located on a wide reach like the Mississippi River, the above methods may assign that intake to a tributary COMID.

As discussed in Chapter 3, EPA did not model more complex waterbodies (*e.g.*, Great Lakes) explicitly. Therefore, the Agency reviewed all intakes within 50 miles of the plants discharging to the Great Lakes or other non-modeled waterbodies to classify intakes that withdraw directly from the non-modeled waterbodies as "Category 3". These intakes are excluded from the subsequent analysis.

Table D-1 summarizes the intake categorization following the above steps.

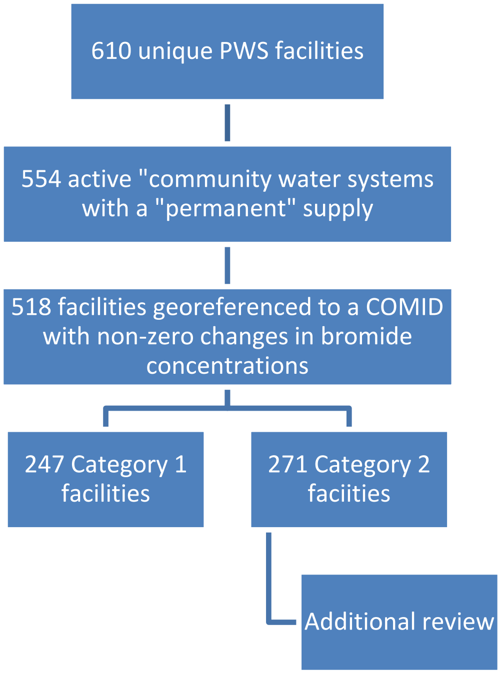
Table D-1: Summary of Intakes Potentially Affected by Steam Electric Power Plant Discharges

Categorization	Number of Intakes
Category 1 (on flow path)	297
Category 2 (within 10 km of flow path) but not Category 1	313
Category 3 (on Great Lakes or other non-modeled waterbodies)	67
Total all categories	**677**

Source: U.S. EPA Analysis, 2019.

Figure D-1 summarizes how EPA subset Category 1 and 2 PWS intakes for a more targeted categorization review.

Figure D-1: PWS Intakes Review Subset



Source: U.S. EPA Analysis, 2020.

EPA evaluated the “Category 2” PWS intakes further using spatial reference to any steam electric downstream flow paths and SDWIS facility information, namely facility name.

EPA excluded intakes from the benefits analysis if they were:

- on an upstream or visually unconnected body of water from the steam electric downstream flow path,
- did not sit on a visible body of water when looking at the topographical maps and/or orthophotos,
- had a PWS facility name indicating that it was not a surface water intake (*i.e.*, included the word “well”).[99]

EPA recategorized intakes as Category 1 if they were:

- on the same NHD waterbody as the steam electric downstream flow path (prominent examples include intakes on Lake Norman, Upper or Lower Potomac River, and Missouri River) or
- the PWS facility name in SDWIS corresponded with the named reach of the steam electric downstream flow path.

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[99] This criterion resulted in the omission of only one facility in Tennessee.

Of the 271 Category 2 facilities that EPA reviewed, 102 facilities were recategorized into Category 1. Therefore, EPA included a total number of 349 PWS intakes[100] in the analysis of the 2019 proposal.

For the final rule analysis, EPA updated the set of surface water intakes potentially affected by steam electric power plant discharges by adding intakes associated with additional reaches identified after the 2019 proposal. This analysis identified one additional intake located on the flowpath downstream from receiving reaches, which EPA included in the analysis described in Section 4.

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[100] Only intakes with facility types categorized by SDWIS as "Intake" or "Reservoir" were retained in the human health benefits analysis. One of the 349 PWS intakes (PWS ID IA9778045) was categorized as "Infiltration Gallery" and was thus not included, bringing the total number of PWS intakes included in the analysis to 348 (see Table 4-1).

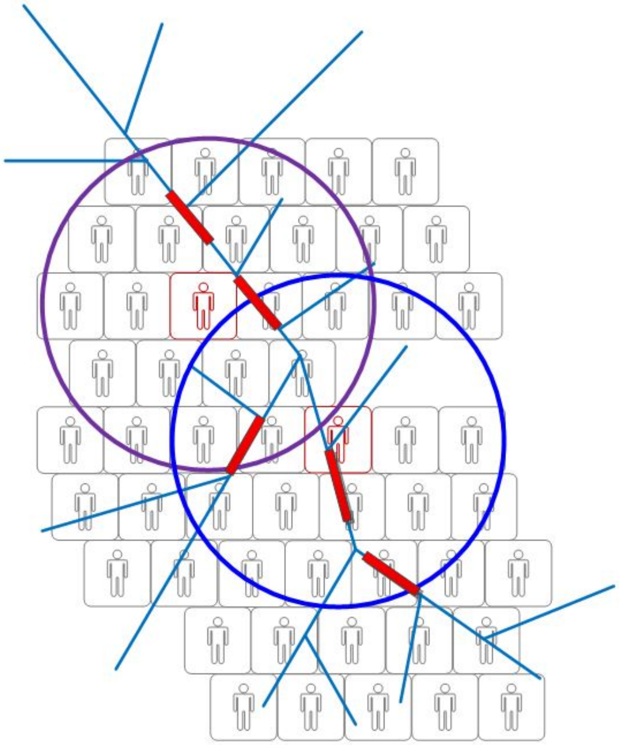
E Estimation of Exposed Population for Fish Ingestion Pathway

The assessment uses the CBG as the geographic unit of analysis, assigning a radial distance (*i.e.*, 50 miles) from the CBG centroid. EPA assumes that all modeled reaches within this range are viable fishing sites, with all unaffected reaches serving as viable substitutes for affected reaches within the area around the Census Block Group.

By focusing on distance from the CBG, rather than distances from affected reaches, each household is only included in the assessment once, eliminating the potential for double-counting of households that are near multiple affected waterbodies.

Figure E-1 presents a hypothetical example focusing on two CBGs (square at the center of each circular area), each near five reaches with water quality changes under the regulatory options (thick red lines).

Figure E-1: Illustration of Intersection of CBGs and Reaches.



Source: U.S. EPA, 2015a.

Note that a similar approach is used to identify populations for the analysis of non-market benefits in Chapter 6. In that case, the circles represent the outer edge of the 100-mile buffer around each CBG.

F Sensitivity Analysis for IQ Point-based Human Health Effects

EPA monetized the value of an IQ point based on the methodology from Salkever (1995) but with more recent data from the 1997 National Longitudinal Survey of Youth (U.S. EPA, 2019b). As a sensitivity analysis of the benefits of changes in lead and mercury exposure, EPA used alternative, more conservative estimates provided in Lin *et al.* (2018) which indicate that a one-point IQ reduction reduces expected lifetime earnings by 1.39 percent, as compared to 2.63 percent based on Salkever (1995). As noted in Sections 5.3 and 5.4, values of an IQ point used in the analysis of health effects in children from lead exposure are discounted to the third year of life to represent the midpoint of the exposed children population, and values of an IQ point used in the analysis of health effects associated with in-utero exposure to mercury are discounted to birth. Table F-1 summarizes the estimated values of an IQ point based on Lin *et al.* (2018), using 3 percent and 7 percent discount rates.

Table F-1: Value of an IQ Point (2018$) based on Expected Reductions in Lifetime Earnings

Discount Rate	Value of an IQ Point[a] (2018$)
	Value of an IQ point Discounted to Age 3
3 percent	$11,279
7 percent	$2,371
	Value of an IQ point Discounted to Birth
3 percent	$10,322
7 percent	$1,936

a. Values are adjusted for the cost of education.

Source: U.S. EPA, 2019b and 2019c analysis of data from Lin et al. (2018)

F.1 Health Effects in Children from Changes in Lead Exposure

Table F-2 shows the monetary values associated with changes in IQ losses from lead exposure via fish consumption. EPA estimated that regulatory options A and B lead to small increases in lead exposure and, as a result, forgone benefits, whereas Option C results in small reductions. The total net change in IQ point losses over the entire population of children with changes in lead exposure ranges from -19 points to 12 points. Annualized monetary values of changes in IQ losses from differences in lead exposure, based on the Lin *et al.* (2018) IQ point value, range from approximately -$9,000 to $4,000 (3 percent discount rate) and from approximately -$2,000 to $400 (7 percent discount rate).

Table F-2: Estimated Monetary Value of Changes in IQ Losses for Children Exposed to Lead under the Regulatory Options, Compared to Baseline

Regulatory Option	Average Annual Number of Children 0 to 7 in Scope of the Analysis[b]	Total Change in IQ Point Losses, 2021 Through 2047 in All Children 0 to 7 in Scope of the Analysis	Annualized Value of Changes in IQ Point Losses[a] (Thousands of 2018$)	
			3 Percent Discount Rate	7 Percent Discount Rate
Option A	1,615,629	-19	-$8.5	-$2.0
Option B	1,615,629	-11	-$5.7	-$1.5
Option C	1,615,629	12	$3.5	$0.4

Table F-2: Estimated Monetary Value of Changes in IQ Losses for Children Exposed to Lead under the Regulatory Options, Compared to Baseline

Regulatory Option	Average Annual Number of Children 0 to 7 in Scope of the Analysis[b]	Total Change in IQ Point Losses, 2021 Through 2047 in All Children 0 to 7 in Scope of the Analysis	Annualized Value of Changes in IQ Point Losses[a] (Thousands of 2018$)	
			3 Percent Discount Rate	7 Percent Discount Rate

a. Based on estimates that the loss of one IQ point results in the loss of 1.39 percent of lifetime earnings (following Lin *et al.* (2018) values from U.S. EPA, 2019b).

b. The number of affected children is based on reaches analyzed across the regulatory options. Some of the children included in this count see no changes in exposure under some options.

Source: U.S. EPA Analysis, 2020

F.2 Heath Effects in Children from Changes in Mercury Exposure

Table F-3 shows the estimated changes in IQ point losses for infants exposed to mercury in-utero and the corresponding monetary values, using 3 percent and 7 percent discount rates. Regulatory options A and B result in a small net increase in IQ losses and, as a result, in forgone benefits to society. Option C results in a small net decrease in IQ point losses (positive benefits), with decreases in Period 2 larger than initial increases in Period 1. However, the annualized monetary value for Option C is negative despite the overall decrease in IQ point losses due to discounting. Annualized monetary values of changes in IQ losses from changes in mercury exposure, based on the Lin *et al.* (2018) IQ point value, range from -$0.17 million (Option A) to -$0.06 million (Option C) using a 3 percent discount rate.

Table F-3: Estimated Monetary Values from Changes in IQ Losses for Infants from Mercury Exposure under the Regulatory Options, Compared to Baseline

Regulatory Option	Number of Infants in Scope of the Analysis per Year[c]	Total Changes in IQ Point Losses, 2021 to 2047 in All Infants in Scope of the Analysis	Annualized Value of Changes in IQ Point Losses[a,b] (Millions 2018$)	
			3 Percent Discount Rate	7 Percent Discount Rate
Option A	225,537	-201	-$0.17	-$0.06
Option B	225,537	-144	-$0.15	-$0.05
Option C	225,537	71[d]	-$0.06	-$0.04

a. Based on estimates that the loss of one IQ point results in the loss of 1.39 percent of lifetime earnings (following Lin *et al.* (2018) values from U.S. EPA, 2019b and 2019c).

b. Negative values represent forgone benefits.

c. The number of affected children is based on reaches analyzed across the regulatory options. Some of the children included in this count see no changes in exposure under some options.

d. Although Option C results in a small net decrease in IQ point losses (or positive benefits) due to larger decreases in Period 2 than initial increases in Period 1, the annualized value for Option C is slightly negative due to discounting.

Source: U.S. EPA Analysis, 2020

G Methodology for Estimating WTP for Water Quality Changes

To estimate the nonmarket benefits of the water quality changes resulting from the regulatory options, EPA used updated results from a meta-analysis of stated preference studies described in detail in Appendix H in the 2015 BCA (U.S. EPA, 2015a). The final rule is estimated to have mixed water quality effects at the reach-level, either positive or negative, depending on the reach and regulatory option. Because the appropriate welfare measure depends on property rights, WTP is the appropriate measure for water improvements, whereas willingness-to-accept (WTA) compensation is the appropriate measure for water quality degradation. EPA used WTP to value both positive and negative water quality changes due to the limited studies measuring WTA. In theory, WTP and WTA should be close to each other for moderate environmental changes. In practice, however, there is a significant divergence between WTA and WTP (Younjun *et al.*, 2015). In particular, WTA for environmental goods tends to be significantly higher compared to WTP (Brown & Gregory, 1999; Horowitz & McConnell, 2002). Brown and Gregory (1999) lists two dozen studies that compared WTA to WTP for environmental goods (*e.g.*, visibility and tree density in parks) and non-environmental goods. The eleven studies of environmental goods included in the paper report WTA:WTP ratios ranging from 2:1 to 5:1, with some ratios substantially higher. Horowitz and McConnell (2002) report a mean ratio of WTA to WTP for non-market goods of 10.41 (standard error 2.53) based on 17 studies. Therefore, using WTP to estimate the monetary value of all water quality changes (positive or negative) under the final rule likely underestimates forgone benefits associated with the final rule. The magnitude of this underestimate is uncertain.

To update results of the 2015 meta-analysis, EPA first conducted a literature review and identified 14 new studies to augment the existing meta-data. EPA then re-estimated the 2015 meta-regression model and made additional improvements to the model by introducing explanatory variables to account for potential publication bias and differences in water quality metrics used in some of the added studies. A memorandum titled *2020 Meta-regression Update Results* (ICF, 2020, DCN SE09335) summarizes EPA's literature review to identify additional studies, meta-data development and coding, model specification, and regression results based on the 2020 meta-data. The 2020 meta-regression results are also briefly summarized below.

Like the 2015 meta-regression model, the updated meta-model satisfies the adding-up condition, a theoretically desirable property.[101] This condition ensures that if the model were used to estimate WTP for the cumulative water quality change resulting from a number of CWA regulations, the benefits estimates would be equal to the sum of benefits from using the model to estimate WTP for water quality changes separately for each rule.

The meta-analysis is based on a meta-dataset of 65 stated preference studies, published between 1985 and 2017. Each of these studies used a stated preference approach to elicit survey respondents' willingness to pay for water quality changes. The variables in the 2015 meta-data fall into four general categories:

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[101] For a WTP function WTP (WQI_0, WQI_2, Y_0) to satisfy the adding-up property, it must meet the simple condition that $WTP(WQI_0, WQI_1 , Y_0) + WTP(WQI_1, WQI_2 , Y_0 - WTP(WQI_0, WQI_1 , Y_0)) = WTP(WQI_0, WQI_2 , Y_0)$ for all possible values of baseline water quality (WQI_0), potential future water quality levels (WQI_1 and WQI_2), and baseline income (Y_0).

1. *Study methodology and year variables* characterize such features as the year in which a study was conducted, payment vehicle and elicitation formats, WTP estimation method, and publication type. These variables are included to explain differences in WTP across studies but are not expected to vary across benefit transfer for different policy applications.

2. *Region and surveyed populations variables* characterize such features as the geographical region within the United States in which the study was conducted, the average income of respondent households and the representation of users and nonusers within the survey sample.

3. *Sampled market and affected resource variables* characterize features such as the geospatial scale (or size) of affected waterbodies, the size of the market area over which populations were sampled, as well as land cover and the quantity of substitute waterbodies.

4. *Water quality (baseline and change) variables* characterize baseline conditions and the extent of the water quality change. To standardize the results across these studies, EPA expressed water quality (baseline and change) in each study using the 100-point WQI, if they did not already employ the WQI or WQL.

In addition to the variables included in the 2015 meta-regression, EPA included two new variables to estimate the updated models. Six of the 14 studies added to the meta-data used a 100-point IBI to specify the baseline and policy scenario conditions of the waterbody in question. These measures differ from the water quality metrics used in the studies included the 2015 meta-data. To account for potential effects of the use of IBI on interpretation of the baseline water quality and expected improvements, EPA included an interaction of a binary variable indicating studies that use the IBI (IBI=1) as the water quality metric with the Q variable (*IBI_Q*).

Following best practices in economic meta-analysis literature, EPA also included the inverse of the square root of sample size (n) as an independent variable on the right-hand side of the model to test for potential publication bias in the meta-regression model. This variable serves as an instrumental variable (IV) or proxy for the standard error (SE) of the welfare estimate (Stanley, 2005; Nelson, 2009).

The two additional variables allowed EPA to more accurately use the new studies while retaining the same meta regression format from the 2015 rule. The variables were termed as follows:

- Interaction of a binary variable (*i.e.*, a variable taking a value of 0 or 1) indicating studies that use the index of biotic integrity (IBI) as the water quality metric with the Q variable (*IBI_Q*). *IBI_Q* = 1 when IBI was used by the study or = 0 otherwise.

- The inverse root of sample size as a proxy for the standard error of the estimate (*inv_rootsz*).

Using the updated meta-dataset, EPA developed a meta-regression model that predicts how marginal WTP for water quality improvements depends on a variety of methodological, population, resource, and water quality change characteristics. The estimated meta-regression model predicts the marginal WTP values that would be generated by a stated preference survey with a particular set of characteristics chosen to represent the water quality changes and other specifics of the regulatory options where possible, and best practices in economic literature (e.g., excluding outlier responses from estimating WTP). As with the 2015 meta-analysis, EPA developed two versions of the meta-regression model (U.S. EPA, 2015a). Model 1 is used to provide EPA's central estimate of non-market benefits and Model 2 is used to develop a range of estimates to account for uncertainty in the resulting WTP values. The two models differ only in how they account for the magnitude of the water quality changes presented to respondents in the original stated preference studies:

- Model 1 assumes that individuals' marginal WTP depends on the level of water quality, but not on the magnitude of the water quality change specified in the survey. This restriction means that the meta-model satisfies the adding-up condition, a theoretically desirable property.
- Model 2 allows marginal WTP to depend not only on the level of water quality but also on the magnitude of the water quality change specified in the survey. The model allows for the possibility that marginal WTP for improving from, for example, 49 to 50 on the water quality index depends on whether respondents were asked to value a total water quality change of 10, 20, or 50 points on a WQI scale. This model provides a better statistical fit to the meta-data, but it satisfies the adding-up conditions only if the same magnitude of the water quality change is considered (*e.g.*, 10 points). To uniquely define the demand curve and satisfy the adding-up condition using this model, EPA treats the water quality change variable as a methodological variable and therefore must make an assumption about the size of the water quality change that would be appropriate to use in a stated preference survey designed to value water quality changes resulting from the regulatory options. When the water quality change is fixed at the mean of the meta-data, the predicted WTP is very close to the central estimate from Model 1.

EPA used the two meta-regression models in a benefit transfer approach that follows standard methods described by (Johnston *et al.* (2005), Shrestha *et al.* (2007), and Rosenberger and Phipps (2007). In particular, literature on benefit transfer recommends selecting values for methodological variables included in the regression equation with the goal of providing conservative WTP estimates, subject to consistency with methodological guidance in the literature. The literature also recommends setting variables representing policy outcomes and policy context (*i.e.*, resource and population characteristics) at the levels that might be expected from a regulation. The benefit transfer approach uses CBGs as the geographic unit of analysis.[102] The transfer approach involved projecting benefits in each CBG and year, based on the following general benefit function:

Equation H-1.

$$\ln(MWTP_{Y,B}) = Intercept + \sum(coefficient_i) \times (independent\ variable\ value_i)$$

Where

$ln(MWTP_{Y,B})$	=	The predicted natural log of marginal household WTP for a given year (*Y*) and CBG (*B*).
coefficient	=	A vector of variable coefficients from the meta-regression.
independent variable values	=	A vector of independent variable values. Variables include baseline water quality level ($WQI\text{-}BL_{Y,B}$) and expected water quality under the regulatory option ($WQI\text{-}PC_{Y,B}$) for a given year and CBG.

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[102] A Census Block group is a group of Census Blocks (the smallest geographic unit for the Census) in a contiguous area that never crosses a State or county boundary. A block group typically contains a population between 600 and 3,000 individuals. There are 217,740 block groups in the 2010 Census. See http://www.census.gov/geo/maps-data/data/tallies/tractblock.html .

Here, $ln(MWTP_{Y,B})$ is the dependent variable in the meta-analysis—the natural log of approximated marginal WTP per household, in a given CBG *B* for water quality in a given year *Y*.[103] The baseline water quality level ($WQI\text{-}BL_{Y,B}$) and expected water quality under the regulatory option ($WQI\text{-}PC_{Y,B}$) were based on water quality in waterbodies within a 100-mile buffer of the centroid of each CBG. A buffer of 100 miles is consistent with Viscusi *et al.* (2008) and with the assumption that the majority of recreational trips would occur within a 2-hour drive from home. Because marginal WTP is assumed to depend, according to Equation H-1, on both baseline water quality level ($WQI\text{-}BL_{Y,B}$) and expected water quality under the regulatory option ($WQI\text{-}PC_{Y,B}$), EPA estimated the marginal WTP for water quality changes resulting from the regulatory options at the mid-point of the range over which water quality was changed, $WQI_{Y,B} = (1/2)(WQI\text{-}BL_{Y,B} + WQI\text{-}PC_{Y,B})$.

In this analysis, EPA estimated WTP for the households in each CBG for waters within a 100-mile radius of that CBG's centroid. EPA chose the 100 mile-radius because households are likely to be most familiar with waterbodies and their qualities within the 100-mile distance. However, this assumption may be an underestimate of the distance beyond which households have familiarity with and WTP for waterbodies affected by steam electric power plant discharges and their quality. By focusing on a buffer around the CBG as a unit of analysis, rather than buffers around affected waterbodies, each household is included in the assessment exactly once, eliminating the potential for double-counting of households.[104] Total national WTP is calculated as the sum of estimated CBG-level WTP across all block groups that have at least one affected waterbody within 100 miles. Using this approach, EPA is unable to analyze the WTP for CBGs with no affected waters within 100 miles. *Appendix E* describes the methodology used to identify the relevant populations.

In each CBG and year, predicted WTP per household is tailored by choosing appropriate input values for the meta-analysis parameters describing the resource(s) valued, the extent of resource changes (*i.e.*, $WQI\text{-}\ PC_{Y,B}$), the scale of resource changes relative to the size of the buffer and relative to available substitutes, the characteristics of surveyed populations (*e.g.*, users, nonusers), and other methodological variables. For example, EPA projected that household income (an independent variable) changes over time, resulting in household WTP values that vary by year.

Table G-1 provides details on how EPA used the meta-analysis to predict household WTP for each CBG and year. The table presents the estimated regression equation intercepts and variable coefficients ($coefficient_i$) for the two models, and the corresponding independent variables names and assigned values. The meta-regression allows the Agency to forecast WTP based on assigned values for model variables that are chosen to represent a resource change in the context of the regulatory options. EPA assigned a value to each model variable corresponding with theory, characteristics of the water resources, and sites potentially affected by the regulatory options. This follows general guidance from Bergstrom and Taylor (2006) that meta-analysis benefit transfer should incorporate theoretical expectations and structures, at least in a weak form.

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[103] To satisfy the adding-up condition, as noted above, EPA normalized WTP values reported in the studies included in the meta-data so that the dependent variable is MWTP per WQI point. This 'average' marginal WTP value is an approximation of the MWTP value elicited in each survey scenario.

[104] Population double-counting issues can arise when using "distance to waterbody" to assess simultaneous improvements to many waterbodies.

In this instance, EPA assigned six study and methodology variables, (*thesis, volunt, nonparam, non_reviewed, lump_sum, and WTP_median*) a value of zero. One methodological variable, *outliers_trim*, was included with an assigned value of 1. Because the interpretation of the study year variable *(Lnyear)* is uncertain, EPA gave the variable a value of 3.2189, which is the 75th percentile of the year values in the meta-data. This value assignment reflects an equal probability that the variable represents a real time trend (in which case its value should be set to the most recent year of the analysis) and spurious effects (in which case its values should be set to the mean value from the meta-data). The choice experiment variable *(ce)* was set to 1 to reflect recent trends in the use of choice experiments within the environmental valuation literature. Finally, the inverse root of sample size (*inv_rootsz*) variable is set to the mean value for studies in the metadata. Model 2 includes an additional variable, water quality change (*ln_quality_ch*), which as discussed above allows the function to reflect differences in marginal WTP based on differences in the magnitude of changes presented to survey respondents when eliciting values. To ensure that the benefit transfer function satisfies the adding-up condition, this variable was treated as a demand curve shifter, similar to the methodological control variables, and held fixed for the benefit calculations. To estimate low and high values of WTP for water quality changes resulting from the regulatory options, EPA estimated marginal WTP using two alternative settings of the *ln_quality* variable: ΔWQI = 5 units and ΔWQI = 50 units, which represent the low and high end of the range of values observed in the meta-data.

All but one of the region and surveyed population variables vary based on the characteristics of each CBG. EPA set the variable *nonusers_only* to zero for all CBGs because water quality changes are expected to enhance both use and non-use values of the affected resources and thus benefit both users and nonusers (a nonuser value of 1 implies WTP values that are representative of nonusers only, whereas the default value of 0 indicates that both users and nonusers are included in the surveyed population). For median household income, EPA used CBG-level median household income data from the 2017 American Community Survey (5-year data) and used a stepwise autoregressive forecasting method to estimate future annual state level median household income.

The geospatial variables corresponding to the sampled market and scale of the affected resources (*ln_ar_agr*, *ln_ar_ratio* , *sub_proportion*) vary based on attributes of the CBG and attributes of the nearby affected resources. For all options, the affected resource is based on the 10,454 NHD reaches potentially affected by steam electric power generating plant discharges under baseline conditions. The affected resource for each CBG is the portion of the 10,454 reaches that falls within the 100-mile buffer of the CBG. Spatial scale is held fixed across regulatory options. The variable corresponding to the sampled market (*ln_ar_ratio*) is set to the mean value across all CBGs included in the analysis of benefits from water quality changes resulting from the regulatory options, and thus does not vary across affected CBGs. To reflect characteristics of the resources included in the analysis (i.e., rivers and streams), EPA set the variable r*iver* to 1 and *mult_type* to 0. Other waterbody types (*e.g.*, Great Lakes, estuaries, enclosed lakes and ponds) are excluded from the analysis.

Because data on specific recreational uses of the water resources affected by the regulatory options are not available, the recreational use variables (*swim_use, gamefish, boat_use*) are set to zero, which corresponds to "unspecified" or "all" recreational uses in the meta-data.[105] Water quality variables (*Q* and *lnquality_ch*) vary across CBGs and regulatory options based on the magnitude of the reach-length weighted average water quality changes in resources within scope of the analysis within the 100-mile buffer of each CBG. Interaction

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[105] If a particular recreational use was not specified in the survey instrument, EPA assesssed that survey respondents were thinking of all relevant uses.

of a binary variable indicating studies that use the IBI as the water quality metric with the Q variable (*IBI_Q*) is set to zero because EPA's analysis of the final rule's benefits relies on the WQI as the water quality metric, not the IBI.

Table G-1: Independent Variable Assignments for Surface Water Quality Meta-Analysis

Variable Type	Variable	Coefficient		Assigned Value	Explanation
		Model 1	Model 2		
Study Methodology and Year	intercept	-1.578	-1.646		
	Ce	0.488	0.329	1	Binary variable indicating that the study is a choice experiment. Set to one to reflect that choice experiments represent current state-of-art methods in stated preference literature.
	thesis	0.634	0.713	0	Binary variable indicating that the study is a thesis or dissertation. Set to zero because studies published in peer-reviewed journals are preferred.
	lnyear	-0.157	-0.209	3.2189	Natural log of the year in which the study was conducted (*i.e.*, data were collected), converted to an index by subtracting 1980. Set to the natural log of the 75th percentile of the year index value for studies in the metadata (25.0) to reflect uncertainty in the variable interpretation. If the variable represents a real time trend, the appropriate value should reflect the most recent year of the analysis. If it represents spurious effects, the values should reflect the mid-point from meta-data. Both interpretations are equally probable.
	volunt	-0.991	-0.842	0	Binary variable indicating that WTP was estimated using a payment vehicle described as voluntary as opposed to, for example, property taxes. Set to zero because hypothetical voluntary payment mechanisms are not incentive compatible (Mitchell and Carson 1989).
	outliers_trim	-0.385	-0.338	1	Binary variable indicating that outlier bids were excluded when estimating WTP. Set to one because WTP estimates that exclude outlier bids are preferable.
	nonparam	-0.577	-0.531	0	Binary variable indicating that regression analysis was not used to model WTP. Set to zero because use of the regression analysis to estimate WTP values is preferred.
	non_reviewed	-0.506	-0.550	0	Binary variable indicating that the study was not published in a peer-reviewed journal. Set to zero because studies published in peer-reviewed journals are preferred.
	lump_sum	0.542	0.486	0	Binary variable indicating that the study provided WTP as a one-time, lump sum or provided annual WTP values for a payment period of five years or less. Set to zero to reflect that the majority of studies from the meta-data estimated an annual WTP, and to produce an annual WTP prediction.

Table G-1: Independent Variable Assignments for Surface Water Quality Meta-Analysis

Variable Type	Variable	Coefficient		Assigned Value	Explanation
		Model 1	Model 2		
	wtp_median	0.156	0.111	0	Binary variable indicating that the WTP measure from the study is the median. Set to zero because only average or mean WTP values in combination with the number of affected households would mathematically yield total benefits if the distribution of WTP is not perfectly symmetrical.
	inv_rootsz	-0.0282	-0.517	0.052	Inverse root of sample size [1 / square root(sample size)], used as a proxy for the standard error of the estimate. Set to the mean value for studies in the metadata.
Region and Surveyed Population	northeast	0.644	0.443	Varies	Binary variable indicating that the affected population is located in a Northeast U.S. state, defined as ME, NH, VT, MA, RI, CT, and NY. Set based on the state in which the CBG is located.
	central	0.672	0.665	Varies	Binary variable indicating that the affected population is located in a Central U.S. state, defined as OH, MI, IN, IL, WI, MN, IA, MO, ND, SD, NE, KS, MT, WY, UT, and CO. Set based on the state in which the CBG is located.
	south	1.489	1.538	Varies	Binary variable indicating that the affected population is located in a Southern U.S. state, defined as NC, SC, GA, FL, KY, TN, MS, AL, AR, LA, OK, TX, and NM. Set based on the state in which the CBG is located.
	nonusers_only	-0.355	-0.355	0	Binary variable indicating that the sampled population included nonusers only; the alternative case includes all households. Set to zero to estimate the total value for aquatic habitat changes for all households, including users and nonusers.
	lnincome	0.312	0.398	Varies	Natural log of median household income values assigned separately for each CBG. Varies by year based on the estimated income growth in future years.
Sampled Market and Affected Resource	mult_type[a]	-0.648	-0.617	0	Binary variable indicating that multiple waterbody types are affected (*e.g.*, river and lakes). Set to zero because calculations are based exclusively on rivers.
	River	0.0196	-0.0213	1	Binary variable indicating that rivers are affected. Set to one because calculations are based exclusively on reach miles. EPA did not estimate water quality changes for other waterbody types (*e.g.*, Great Lakes, estuaries, and enclosed lakes and ponds).
	swim_use	0.0110	0.0405	0	Binary variables that identify studies in which swimming, gamefish, and boating uses are specifically identified. Since data on specific recreational uses of the reaches affected by steam electric power plant discharges are not available, set to zero, which corresponds to all recreational uses.
	Gamefish	0.557	0.475	0	
	boat_use	-0.889	-0.786	0	

Table G-1: Independent Variable Assignments for Surface Water Quality Meta-Analysis

Variable Type	Variable	Coefficient		Assigned Value	Explanation
		Model 1	Model 2		
	ln_ar_agr	-0.621	-0.630	Varies	Natural log of the proportion of the affected resource area which is agricultural based on National Land Cover Database, reflecting the nature of development in the area surrounding the resource. Used Census county boundary layers to identify counties that intersect affected resources within the 100-mile buffer of each CBG. For intersecting counties, calculated the fraction of total land area that is agricultural using the National Land Cover Dataset (NLCD). The *ln_ar_agr* variable was coded in the metadata to reflect the area surrounding the affected resources.
	ln_ar_ratio	-0.0891	-0.0939	1.491	The natural log of the ratio of the sampled area (*sa_area*) relative to the affected resource area (defined as the total area of counties that intersect the affected resource[s]) (*ar_total_area*). In the context of the steam electric scenario, *sa_area* is set based on the total area within the 100-mile buffer from the CBGs in scope of the analysis (31,415 mi^2) and the area of counties that intersect affected reaches (COMIDs) within the 100-mile radius. ln_ar_ratio is set to the mean value from the all CBG's containing waters within the scope of the analysis.
	sub_proportion	1.261	0.975	Varies	The size of the resources within the scope of the analysis relative to available substitutes. Calculated as the ratio of affected reaches miles to the total number of reach miles within the buffer that are the same or greater than the order(s) of the affected reaches within the buffer. Its value can range from 0 to 1.
Water Quality	Q	-0.0215	-0.0167	Varies	Because marginal WTP is assumed to depend on both baseline water quality and expected water quality under the regulatory option, this variable is set to the mid-point of the range of water quality changes due to the regulatory options, $WQI_{Y,B} = (1/2)(WQI\text{-}BL_{Y,B} + WQI\text{-}PC_{Y,B})$. Calculated as the length-weighted average WQI score for all potentially affected reaches within the 100-mile buffer of each CBG.
	lnquality_ch	NA	-0.314	ln(5) or ln(50)	*Ln_quality_ch* was set to the natural log of ΔWQI=5 or ΔWQI=50 for high and low estimates of the marginal WTP, respectively.
	IBI_Q	-0.0502	-0.0463	0	Interaction of a Binary variable indicating studies that use the IBI as the water quality metric with the Q variable. Set to zero because the meta-regression uses the WQI as the water quality metric, not the IBI.

Table G-1: Independent Variable Assignments for Surface Water Quality Meta-Analysis

Variable Type	Variable	Coefficient		Assigned Value	Explanation
		Model 1	Model 2		

a. The meta-data includes six waterbody categories (1) river and stream, (2) lake, (3) all freshwater, (4) estuary, (5) river and lake, (6) salt pond/marshes, Variable *multi-type* takes on a value of 1 if the study focused on waterbody categories (3) and (6). EPA notes that the overall effect of this variable should be considered in conjunction with the regional dummies (*e.g.*, a study of the Lake Okeechobee basin in Florida) and that only eight percent of all observations in the meta-data fall in the multiple waterbody categories.

Source: U.S. EPA Analysis, 2020

The estimates for total WTP are shown in Table 6-2. EPA presents the results as a range because a water quality change of +5 is closer to the size of water quality changes projected to result from the regulatory options than the +20 analog to the central estimate, while the +50 represents the upper end of water quality changes in existing surveys. In estimating forgone benefits (*i.e.*, negative WTP estimates), +5 represents the lower end of the sensitivity range, while the +50 represents the higher end of the sensitivity range.

H Identification of Threatened and Endangered Species Potentially Affected by the Final Rule Regulatory Options

As discussed in Chapter 7, EPA identified a total of 197 T&E species whose habitat range intersects reaches affected by steam electric power plant discharges. These species include amphibians, arachnids, birds, clams, crustaceans, fishes, insects, mammals, reptiles, and snails. Table H-1 summarizes the number of species within each group that have habitat ranges intersecting reaches with NRWQC exceedances for at least one pollutant under the baseline or regulatory options in Period 1 (2021-2028) or Period 2 (2029-2047). As shown in the table, several species of birds, clams, fishes, mammals, and snails have habitat ranges overlapping reaches with baseline exceedances in Period 1. Additional species have exceedances under regulatory options (Option C), but not the baseline (*e.g.*, one species of amphibians, 2 species of birds, and 1 species of mammals).

Water quality improvements in Period 2 generally eliminate exceedances under the baseline and regulatory options, with the exception of one species of fish[106] whose habitat range intersects reaches with remaining baseline exceedances in Period 2.

Table H-1: Number of T&E Species with Habitat Range Intersecting Reaches Downstream from Steam Electric Power Plant Outfalls, by Species Group

Species Group	Species Count	Number of Species with Habitat Range Intersecting Reaches with NRWQC Exceedances for at Least One Pollutant							
		Period 1				Period 2			
		Baseline	Option A	Option B	Option C	Baseline	Option A	Option B	Option C
Amphibians	8	0	0	0	1	0	0	0	0
Arachnids	6	0	0	0	0	0	0	0	0
Birds	25	3	3	3	5	0	0	0	0
Clams	62	16	17	17	17	0	0	0	0
Crustaceans	5	0	0	0	0	0	0	0	0
Fishes	35	7	7	7	7	1	0	0	0
Insects	10	0	0	0	0	0	0	0	0
Mammals	16	3	3	3	4	0	0	0	0
Reptiles	19	0	0	0	0	0	0	0	0
Snails	11	1	1	1	1	0	0	0	0
Total	**197**	**30**	**31**	**31**	**35**	**1**	**0**	**0**	**0**

Source: U.S. EPA Analysis, 20202

Table H-2 provides further details on the 197 T&E species whose habitat range intersects reaches affected by steam electric power plant discharges. The table denotes, for each species, the number of reaches with at least one reported exceedance of a NRWQC in the baseline or regulatory options in Period 1 and Period 2. The table also includes the results of EPA's assessment of species vulnerability to water pollution. As noted in Chapter 7, EPA classified species as follows:

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[106] As shown in Table H-2, *Etheostoma trisella* (Trispot darter) has baseline exceedances in Period 2.

- Higher vulnerability – species living in aquatic habitats for several life history stages and/or species that obtain a majority of their food from aquatic sources.
- Moderate vulnerability – species living in aquatic habitats for one life history stage and/or species that obtain some of their food from aquatic sources.
- Lower vulnerability – species whose habitats overlap bodies of water, but whose life history traits and food sources are terrestrial.

EPA obtained species life history data from a wide variety of sources to assess T&E species vulnerability to water pollution. These sources included U.S. DOI, 2019; Froese and Pauly, 2019; NatureServe, 2020; NOAA Fisheries, 2020; Southwest Fisheries Science Center (SWFSC), 2019; U.S. FWS, 2019a, 2019b, 2019c, 2019d, 2019e, 2019f, 2019g, 2020a, 2020b, 2020c, 2020e, 2020f, 2020g, 2020h, 2020i, 2020j, 2020k; Upper Colorado River Endangered Fish Recovery Program, 2020.

Section 7.3.2 discusses impacts on five higher vulnerability species whose habitat ranges intersect reaches with estimated changes in NRWQC exceedance status under the regulatory options.

Table H-2: T&E Species with Habitat Range Intersecting Reaches Downstream from Steam Electric Power Plant Outfalls

Species Group	Species Count	Species Name	Vulnerability	Number of Intersected Reaches Exceeding NRWQC for at Least One Pollutant							
				Period 1				Period 2			
				Baseline	Option A	Option B	Option C	Baseline	Option A	Option B	Option C
Amphibians	8	*Ambystoma bishopi*	Moderate	0	0	0	0	0	0	0	0
		Ambystoma cingulatum	Moderate	0	0	0	1	0	0	0	0
		Cryptobranchus alleganiensis bishopi	Higher	0	0	0	0	0	0	0	0
		Necturus alabamensis	Higher	0	0	0	0	0	0	0	0
		Phaeognathus hubrichti	Lower	0	0	0	0	0	0	0	0
		Plethodon nettingi	Lower	0	0	0	0	0	0	0	0
		Rana pretiosa	Higher	0	0	0	0	0	0	0	0
		Rana sevosa	Lower	0	0	0	0	0	0	0	0
Arachnids	6	*Cicurina baronia*	Lower	0	0	0	0	0	0	0	0
		Cicurina madla	Lower	0	0	0	0	0	0	0	0
		Cicurina venii	Lower	0	0	0	0	0	0	0	0
		Cicurina vespera	Lower	0	0	0	0	0	0	0	0
		Neoleptoneta microps	Lower	0	0	0	0	0	0	0	0
		Texella cokendolpheri	Lower	0	0	0	0	0	0	0	0
Birds	25	*Ammodramus savannarum floridanus*	Lower	0	0	0	0	0	0	0	0
		Aphelocoma coerulescens	Lower	0	0	0	0	0	0	0	0
		Brachyramphus marmoratus	Moderate	0	0	0	0	0	0	0	0
		Calidris canutus rufa	Lower	0	0	0	0	0	0	0	0
		Campephilus principalis	Lower	0	0	0	0	0	0	0	0
		Charadrius melodus	Moderate	5	5	5	5	0	0	0	0
		Coccyzus americanus	Lower	7	9	9	9	0	0	0	0
		Dendroica chrysoparia	Lower	0	0	0	0	0	0	0	0
		Empidonax traillii extimus	Lower	0	0	0	0	0	0	0	0

Table H-2: T&E Species with Habitat Range Intersecting Reaches Downstream from Steam Electric Power Plant Outfalls

Species Group	Species Count	Species Name	Vulnerability	Number of Intersected Reaches Exceeding NRWQC for at Least One Pollutant							
				Period 1				Period 2			
				Baseline	Option A	Option B	Option C	Baseline	Option A	Option B	Option C
		Eremophila alpestris strigata	Lower	0	0	0	0	0	0	0	0
		Falco femoralis septentrionalis	Lower	0	0	0	0	0	0	0	0
		Grus americana	Moderate	0	0	0	0	0	0	0	0
		Grus canadensis pulla	Moderate	0	0	0	0	0	0	0	0
		Gymnogyps californianus	Lower	0	0	0	0	0	0	0	0
		Mycteria americana	Moderate	0	0	0	1	0	0	0	0
		Numenius borealis	Lower	0	0	0	0	0	0	0	0
		Phoebastria (=Diomedea) albatrus	Lower	0	0	0	0	0	0	0	0
		Picoides borealis	Lower	0	0	0	1	0	0	0	0
		Polyborus plancus audubonii	Lower	0	0	0	0	0	0	0	0
		Rostrhamus sociabilis plumbeus	Lower	0	0	0	0	0	0	0	0
		Sterna antillarum	Higher	5	5	5	5	0	0	0	0
		Sterna dougallii dougallii	Lower	0	0	0	0	0	0	0	0
		Strix occidentalis lucida	Lower	0	0	0	0	0	0	0	0
		Tympanuchus cupido attwateri	Lower	0	0	0	0	0	0	0	0
		Vermivora bachmanii	Moderate	0	0	0	0	0	0	0	0
Clams	62	*Amblema neislerii*	Higher	0	0	0	0	0	0	0	0
		Cumberlandia monodonta	Higher	1	1	1	1	0	0	0	0
		Cyprogenia stegaria	Higher	1	1	1	1	0	0	0	0
		Dromus dromas	Higher	1	1	1	1	0	0	0	0
		Elliptio chipolaensis	Higher	0	0	0	0	0	0	0	0
		Elliptio lanceolata	Higher	0	0	0	0	0	0	0	0
		Elliptio spinosa	Higher	0	0	0	0	0	0	0	0
		Elliptoideus sloatianus	Higher	0	0	0	0	0	0	0	0
		Epioblasma brevidens	Higher	0	0	0	0	0	0	0	0
		Epioblasma capsaeformis	Higher	0	0	0	0	0	0	0	0
		Epioblasma florentina florentina	Higher	0	0	0	0	0	0	0	0
		Epioblasma florentina walkeri (=E. walkeri)	Higher	0	0	0	0	0	0	0	0
		Epioblasma metastriata	Higher	0	0	0	0	0	0	0	0
		Epioblasma obliquata obliquata	Higher	0	0	0	0	0	0	0	0
		Epioblasma othcaloogensis	Higher	0	0	0	0	0	0	0	0
		Epioblasma torulosa gubernaculum	Higher[a]	1	1	1	1	0	0	0	0
		Epioblasma torulosa rangiana	Higher	0	0	0	0	0	0	0	0
		Epioblasma torulosa torulosa	Higher	0	0	0	0	0	0	0	0
		Epioblasma triquetra	Higher	0	0	0	0	0	0	0	0
		Epioblasma turgidula	Higher	0	0	0	0	0	0	0	0
		Fusconaia cor	Higher	1	1	1	1	0	0	0	0

Table H-2: T&E Species with Habitat Range Intersecting Reaches Downstream from Steam Electric Power Plant Outfalls

Species Group	Species Count	Species Name	Vulnerability	Number of Intersected Reaches Exceeding NRWQC for at Least One Pollutant							
				Period 1				Period 2			
				Baseline	Option A	Option B	Option C	Baseline	Option A	Option B	Option C
		Fusconaia cuneolus	Higher	1	1	1	1	0	0	0	0
		Hemistena lata	Higher	1	1	1	1	0	0	0	0
		Lampsilis abrupta	Higher	1	1	1	1	0	0	0	0
		Lampsilis altilis	Higher	0	0	0	0	0	0	0	0
		Lampsilis higginsii	Higher	0	0	0	0	0	0	0	0
		Lampsilis perovalis	Higher	0	0	0	0	0	0	0	0
		Lampsilis rafinesqueana	Higher	0	0	0	0	0	0	0	0
		Lampsilis subangulata	Higher	0	0	0	0	0	0	0	0
		Lampsilis virescens	Higher	1	1	1	1	0	0	0	0
		Lasmigona decorata	Higher	0	0	0	0	0	0	0	0
		Lemiox rimosus	Higher	1	1	1	1	0	0	0	0
		Leptodea leptodon	Higher	0	0	0	0	0	0	0	0
		Margaritifera hembeli	Higher	0	0	0	0	0	0	0	0
		Margaritifera marrianae	Higher	0	0	0	0	0	0	0	0
		Medionidus acutissimus	Higher	0	0	0	0	0	0	0	0
		Medionidus parvulus	Higher	0	0	0	0	0	0	0	0
		Medionidus penicillatus	Higher	0	0	0	0	0	0	0	0
		Obovaria retusa	Higher	1	1	1	1	0	0	0	0
		Plethobasus cicatricosus	Higher	1	1	1	1	0	0	0	0
		Plethobasus cooperianus	Higher	1	1	1	1	0	0	0	0
		Plethobasus cyphyus	Higher	1	1	1	1	0	0	0	0
		Pleurobema clava	Higher	0	1	1	1	0	0	0	0
		Pleurobema collina	Higher	0	0	0	0	0	0	0	0
		Pleurobema decisum	Higher	0	0	0	0	0	0	0	0
		Pleurobema furvum	Higher	0	0	0	0	0	0	0	0
		Pleurobema georgianum	Higher	0	0	0	0	0	0	0	0
		Pleurobema hanleyianum	Higher	0	0	0	0	0	0	0	0
		Pleurobema perovatum	Higher	0	0	0	0	0	0	0	0
		Pleurobema plenum	Higher	1	1	1	1	0	0	0	0
		Pleurobema pyriforme	Higher	0	0	0	0	0	0	0	0
		Pleurobema taitianum	Higher	0	0	0	0	0	0	0	0
		Pleuronaia dolabelloides	Higher	0	0	0	0	0	0	0	0
		Potamilus capax	Higher	0	0	0	0	0	0	0	0
		Potamilus inflatus	Higher	0	0	0	0	0	0	0	0
		Ptychobranchus greenii	Higher	0	0	0	0	0	0	0	0
		Quadrula cylindrica cylindrica	Higher	0	0	0	0	0	0	0	0
		Quadrula cylindrica strigillata	Higher[b]	1	1	1	1	0	0	0	0
		Quadrula fragosa	Higher	0	0	0	0	0	0	0	0
		Quadrula intermedia	Higher	0	0	0	0	0	0	0	0
		Villosa fabalis	Higher[b]	0	0	0	0	0	0	0	0
		Villosa perpurpurea	Higher	0	0	0	0	0	0	0	0
Crustaceans	5	*Antrolana lira*	Higher	0	0	0	0	0	0	0	0
		Cambarus aculabrum	Higher	0	0	0	0	0	0	0	0
		Gammarus acherondytes	Moderate	0	0	0	0	0	0	0	0

Table H-2: T&E Species with Habitat Range Intersecting Reaches Downstream from Steam Electric Power Plant Outfalls

Species Group	Species Count	Species Name	Vulnerability	Number of Intersected Reaches Exceeding NRWQC for at Least One Pollutant							
				Period 1				Period 2			
				Baseline	Option A	Option B	Option C	Baseline	Option A	Option B	Option C
		Orconectes shoupi[c]	Higher	0	0	0	0	0	0	0	0
		Palaemonias alabamae	Moderate	0	0	0	0	0	0	0	0
Fishes	35	*Acipenser oxyrinchus (=oxyrhynchus) desotoi*	Higher	0	0	0	0	0	0	0	0
		Amblyopsis rosae	Higher	0	0	0	0	0	0	0	0
		Chrosomus saylori	Higher[b]	0	0	0	0	0	0	0	0
		Cottus specus	Higher[b]	0	0	0	0	0	0	0	0
		Cyprinella caerulea	Higher	0	0	0	0	0	0	0	0
		Elassoma alabama	Higher[b]	0	0	0	0	0	0	0	0
		Erimonax monachus	Higher	0	0	0	0	0	0	0	0
		Erimystax cahni	Higher	1	1	1	1	0	0	0	0
		Etheostoma boschungi	Higher	0	0	0	0	0	0	0	0
		Etheostoma chienense	Higher	0	0	0	0	0	0	0	0
		Etheostoma etowahae	Higher	0	0	0	0	0	0	0	0
		Etheostoma nianguae	Higher	0	0	0	0	0	0	0	0
		Etheostoma osburni	Higher[b]	0	0	0	0	0	0	0	0
		Etheostoma phytophilum	Higher	0	0	0	0	0	0	0	0
		Etheostoma rubrum	Higher	0	0	0	0	0	0	0	0
		Etheostoma scotti	Higher	0	0	0	0	0	0	0	0
		Etheostoma sellare	Higher	0	0	0	0	0	0	0	0
		Etheostoma trisella	Higher	4	4	4	4	3	0	0	0
		Fundulus julisia	Higher[b]	1	1	1	1	0	0	0	0
		Gila cypha	Higher	7	9	9	9	0	0	0	0
		Gila elegans	Higher	0	0	0	0	0	0	0	0
		Notropis cahabae	Higher	0	0	0	0	0	0	0	0
		Notropis girardi	Higher	0	0	0	0	0	0	0	0
		Notropis topeka (=tristis)	Higher	5	5	5	5	0	0	0	0
		Noturus flavipinnis	Higher	1	1	1	1	0	0	0	0
		Oncorhynchus clarkii stomias	Higher	0	0	0	0	0	0	0	0
		Percina aurora	Higher	0	0	0	0	0	0	0	0
		Percina rex	Higher	0	0	0	0	0	0	0	0
		Percina tanasi	Higher	0	0	0	0	0	0	0	0
		Ptychocheilus lucius	Higher	7	9	9	9	0	0	0	0
		Salvelinus confluentus	Higher	0	0	0	0	0	0	0	0
		Scaphirhynchus albus	Higher	0	0	0	0	0	0	0	0
		Scaphirhynchus suttkusi	Higher	0	0	0	0	0	0	0	0
		Speoplatyrhinus poulsoni	Higher[b]	0	0	0	0	0	0	0	0
		Xyrauchen texanus	Higher	0	0	0	0	0	0	0	0
Insects	10	*Batrisodes venyivi*	Lower	0	0	0	0	0	0	0	0
		Bombus affinis	Lower	0	0	0	0	0	0	0	0
		Cicindelidia floridana	Lower	0	0	0	0	0	0	0	0
		Hesperia dacotae	Lower	0	0	0	0	0	0	0	0
		Lycaeides melissa samuelis	Lower	0	0	0	0	0	0	0	0

Table H-2: T&E Species with Habitat Range Intersecting Reaches Downstream from Steam Electric Power Plant Outfalls

Species Group	Species Count	Species Name	Vulnerability	Number of Intersected Reaches Exceeding NRWQC for at Least One Pollutant							
				Period 1				Period 2			
				Baseline	Option A	Option B	Option C	Baseline	Option A	Option B	Option C
		Neonympha mitchellii mitchellii	Lower	0	0	0	0	0	0	0	0
		Nicrophorus americanus	Lower	0	0	0	0	0	0	0	0
		Rhadine exilis	Lower	0	0	0	0	0	0	0	0
		Rhadine infernalis	Lower	0	0	0	0	0	0	0	0
		Somatochlora hineana	Higher	0	0	0	0	0	0	0	0
Mammals	16	*Canis lupus*	Lower	0	0	0	0	0	0	0	0
		Corynorhinus (=Plecotus) townsendii ingens	Lower	0	0	0	0	0	0	0	0
		Corynorhinus (=Plecotus) townsendii virginianus	Lower	0	0	0	0	0	0	0	0
		Herpailurus (=Felis) yagouaroundi cacomitli	Lower	0	0	0	0	0	0	0	0
		Leopardus (=Felis) pardalis	Lower	0	0	0	0	0	0	0	0
		Lynx canadensis	Lower	0	0	0	0	0	0	0	0
		Mustela nigripes	Lower	0	0	0	0	0	0	0	0
		Myotis grisescens	Moderate	1	2	2	2	0	0	0	0
		Myotis septentrionalis	Lower	8	9	9	10	0	0	0	0
		Myotis sodalis	Lower	3	4	4	4	0	0	0	0
		Peromyscus polionotus phasma	Lower	0	0	0	0	0	0	0	0
		Puma (=Felis) concolor coryi	Lower	0	0	0	0	0	0	0	0
		Thomomys mazama pugetensis	Lower	0	0	0	0	0	0	0	0
		Thomomys mazama tumuli	Lower	0	0	0	0	0	0	0	0
		Thomomys mazama yelmensis	Lower	0	0	0	0	0	0	0	0
		Trichechus manatus	Higher	0	0	0	1	0	0	0	0
Reptiles	19	*Caretta caretta*	Lower	0	0	0	0	0	0	0	0
		Chelonia mydas	Lower	0	0	0	0	0	0	0	0
		Clemmys muhlenbergii	Moderate	0	0	0	0	0	0	0	0
		Crocodylus acutus	Lower	0	0	0	0	0	0	0	0
		Dermochelys coriacea	Lower	0	0	0	0	0	0	0	0
		Drymarchon corais couperi	Lower	0	0	0	0	0	0	0	0
		Eretmochelys imbricata	Lower	0	0	0	0	0	0	0	0
		Eumeces egregius lividus	Lower	0	0	0	0	0	0	0	0
		Gopherus polyphemus	Lower	0	0	0	0	0	0	0	0
		Graptemys flavimaculata	Higher	0	0	0	0	0	0	0	0
		Lepidochelys kempii	Lower	0	0	0	0	0	0	0	0
		Neoseps reynoldsi	Lower	0	0	0	0	0	0	0	0
		Pituophis melanoleucus lodingi	Lower	0	0	0	0	0	0	0	0
		Pituophis ruthveni	Lower	0	0	0	0	0	0	0	0
		Pseudemys alabamensis	Higher	0	0	0	0	0	0	0	0
		Sistrurus catenatus	Lower	0	0	0	0	0	0	0	0

Table H-2: T&E Species with Habitat Range Intersecting Reaches Downstream from Steam Electric Power Plant Outfalls

Species Group	Species Count	Species Name	Vulnerability	Number of Intersected Reaches Exceeding NRWQC for at Least One Pollutant							
				Period 1				Period 2			
				Baseline	Option A	Option B	Option C	Baseline	Option A	Option B	Option C
		Sternotherus depressus	Higher	0	0	0	0	0	0	0	0
		Thamnophis eques megalops	Lower	0	0	0	0	0	0	0	0
		Thamnophis rufipunctatus	Lower	0	0	0	0	0	0	0	0
Snails	11	*Athearnia anthonyi*	Higher	1	1	1	1	0	0	0	0
		Campeloma decampi	Higher	0	0	0	0	0	0	0	0
		Discus macclintocki	Lower	0	0	0	0	0	0	0	0
		Elimia crenatella	Higher	0	0	0	0	0	0	0	0
		Leptoxis foremani	Higher	0	0	0	0	0	0	0	0
		Leptoxis taeniata	Higher	0	0	0	0	0	0	0	0
		Lioplax cyclostomaformis	Higher	0	0	0	0	0	0	0	0
		Pleurocera foremani	Higher	0	0	0	0	0	0	0	0
		Pyrgulopsis ogmorhaphe	Higher	0	0	0	0	0	0	0	0
		Triodopsis platysayoides	Lower	0	0	0	0	0	0	0	0
		Tulotoma magnifica	Higher	0	0	0	0	0	0	0	0

[a] This species is presumed extinct.

[b] While this species is categorized as highly vulnerable to water quality changes, it is endemic to waters (headwater streams and springs) that are not likely to receive discharges from steam electric plants or be affected by upstream discharges. EPA did not include this species in the set of T&E species with benefits or forgone benefits as a result of the final rule.

[c] U.S. Fish and Wildlife Service proposed delisting this species on 11/26/2019. See notice of proposed rulemaking “Endangered and Threatened Wildlife and Plants: Removal of the Nashville Crayfish from the Federal List of Endangered and Threatened Wildlife.” (84 FR 65098)

Source: U.S. EPA Analysis, 2020

I Uncertainty Associated with Estimating the Social Cost of Carbon

The methodology used to develop interim domestic SC-CO_2 estimates and uncertainty associated with the interim SC-CO_2 values are the same as described in the RIA for the Affordable Clean Energy (ACE) final rule (see U.S. EPA, 2019i). This appendix applies the methodology to the analysis of the climate benefits of changes in CO_2 emissions under the regulatory options described in Chapter 8.

I.1 Overview of Methodology Used to Develop Interim Domestic SC-CO_2 Estimates

The domestic SC-CO_2 estimates rely on the same ensemble of three integrated assessment models (IAMs) that were used to develop the global SC-CO_2 estimates (DICE 2010, FUND 3.8, and PAGE 2009)[107] used in the benefits analysis of the 2015 rule (see U.S. EPA, 2015a). The three IAMs translate emissions into changes in atmospheric greenhouse concentrations, atmospheric concentrations into changes in temperature, and changes in temperature into economic damages. The emissions projections used in the models are based on specified socioeconomic (GDP and population) pathways. These emissions are translated into atmospheric concentrations, and concentrations are translated into warming based on each model's simplified representation of the climate and a key parameter, equilibrium climate sensitivity. The effect of the changes is estimated in terms of consumption-equivalent economic damages. As in the estimation of SC-CO_2 estimates used in the 2015 benefits analysis (U.S. EPA, 2015a), three key inputs were harmonized across the three models: a probability distribution for equilibrium climate sensitivity; five scenarios for economic, population, and emissions growth; and discount rates.[108] All other model features were left unchanged. Future damages are discounted using constant discount rates of both 3 and 7 percent, as recommended by OMB Circular A-4. The domestic share of the global SC-CO_2 – *i.e.*, an approximation of the climate change impacts that occur within U.S. borders – are calculated directly in both FUND and PAGE. However, DICE 2010 generates only global SC-CO_2 estimates. Therefore, EPA approximated U.S. damages as 10 percent of the global values from the DICE model runs, based on the results from a regionalized version of the model (RICE 2010) reported in Table 2 of Nordhaus (2017).

The steps involved in estimating the social cost of CO_2 are as follows. The three integrated assessment models (FUND, DICE, and PAGE) are run using the harmonized equilibrium climate sensitivity distribution, five socioeconomic and emissions scenarios, and constant discount rates described above. Because the climate sensitivity parameter is modeled probabilistically, and because PAGE and FUND incorporate uncertainty in other model parameters, the final output from each model run is a distribution over the SC-CO_2 in year *t* based on a Monte Carlo simulation of 10,000 runs. For each of the IAMs, the basic computational steps for calculating the social cost estimate in a particular year *t* are:

1. calculate the temperature effects and (consumption-equivalent) damages in each year resulting from the baseline path of emissions;
2. adjust the model to reflect an additional unit of emissions in year *t*;

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[107] The full model names are as follows: Dynamic Integrated Climate and Economy (DICE); Climate Framework for Uncertainty, Negotiation, and Distribution (FUND); and Policy Analysis of the Greenhouse Gas Effect (PAGE).

[108] See the summary of the methodology in the 2015 Clean Power Plan docket, document ID number EPA-HQ-OAR-2013-0602-37033, "Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866, Interagency Working Group on Social Cost of Carbon United States Government, 2015. See also National Academies of Sciences & Medicine, 2017 for a detailed discussion of each of these modeling assumptions.

3. recalculate the temperature effects and damages expected in all years beyond *t* resulting from this adjusted path of emissions, as in step 1; and
4. subtract the damages computed in step 1 from those in step 3 in each model period and discount the resulting path of marginal damages back to the year of emissions. In PAGE and FUND step 4 focuses on the damages attributed to the US region in the models. As noted above, DICE does not explicitly include a separate US region in the model and therefore, EPA approximates U.S. damages in step 4 as 10 percent of the global values based on the results of Nordhaus (2017).

This exercise produces 30 separate distributions of the SC-CO_2 for a given year, the product of 3 models, 2 discount rates, and 5 socioeconomic scenarios. Following the approach used by the IWG, the estimates are equally weighted across models and socioeconomic scenarios in order to reduce the dimensionality of the results down to two separate distributions, one for each discount rate.

I.2 Treatment of Uncertainty in Interim Domestic SC-CO_2 Estimates

There are various sources of uncertainty in the SC-CO_2 estimates used in this BCA. Some uncertainties pertain to aspects of the natural world, such as quantifying the physical effects of greenhouse gas emissions on Earth systems. Other sources of uncertainty are associated with current and future human behavior and well-being, such as population and economic growth, GHG emissions, the translation of Earth system changes to economic damages, and the role of adaptation. It is important to note that even in the presence of uncertainty, scientific and economic analysis can provide valuable information to the public and decision makers, though the uncertainty should be acknowledged and when possible taken into account in the analysis (Institute of Medicine, 2013). OMB Circular A-4 also requires a thorough discussion of key sources of uncertainty in the calculation of benefits and costs, including more rigorous quantitative approaches for higher consequence rules. This section summarizes the sources of uncertainty considered in a quantitative manner in the domestic SC-CO_2 estimates.

The domestic SC-CO_2 estimates consider various sources of uncertainty through a combination of a multi-model ensemble, probabilistic analysis, and scenario analysis. EPA provides a summary of this analysis here; more detailed discussion of each model and the harmonized input assumptions can be found in the 2017 National Academies report. For example, the three IAMs used collectively span a wide range of Earth system and economic outcomes to help reflect the uncertainty in the literature and in the underlying dynamics being modeled. The use of an ensemble of three different models at least partially addresses the fact that no single model includes all of the quantified economic damages. It also helps to reflect structural uncertainty across the models, which is uncertainty in the underlying relationships between GHG emissions, Earth systems, and economic damages that are included in the models. Bearing in mind the different limitations of each model and lacking an objective basis upon which to differentially weight the models, the three integrated assessment models are given equal weight in the analysis.

Monte Carlo techniques were used to run the IAMs a large number of times. In each simulation the uncertain parameters are represented by random draws from their defined probability distributions. In all three models the equilibrium climate sensitivity is treated probabilistically based on the probability distribution from Roe and Baker (2007) calibrated to the Intergovernmental Panel on Climate Change (IPCC) AR4 consensus statement about this key parameter.[109] The equilibrium climate sensitivity is a key parameter in this analysis because it helps define the strength of the climate response to increasing GHG concentrations in the atmosphere. In addition, the FUND and PAGE models define many of their parameters with probability distributions instead of point estimates. For these two models, the model developers' default probability distributions are maintained for all parameters other than those superseded by the harmonized inputs (*i.e.*, equilibrium climate sensitivity, socioeconomic and emissions scenarios, and discount rates). More information on the uncertain parameters in PAGE and FUND is available upon request.

For the socioeconomic and emissions scenarios, uncertainty is included in the analysis by considering a range of scenarios selected from the Stanford Energy Modeling Forum exercise, EMF-22. Given the dearth of information on the likelihood of a full range of future socioeconomic pathways at the time the original modeling was conducted, and without a basis for assigning differential weights to scenarios, the range of uncertainty was reflected by simply weighting each of the five scenarios equally for the consolidated estimates. To better understand how the results vary across scenarios, results of each model run are available in the docket for the ACE final rule (Docket ID EPA-HQ-OAR-2017-0355).

The outcome of accounting for various sources of uncertainty using the approaches described above is a frequency distribution of the SC-CO_2 estimates for emissions occurring in a given year for each discount rate. Unlike the approach taken for consolidating results across models and socioeconomic and emissions scenarios, the SC-CO_2 estimates are not pooled across different discount rates because the range of discount rates reflects both uncertainty and, at least in part, different policy or value judgements; uncertainty regarding this key assumption is discussed in more detail below. The frequency distributions reflect the uncertainty around the input parameters for which probability distributions were defined, as well as from the multi-model ensemble and socioeconomic and emissions scenarios where probabilities were implied by the equal weighting assumption. It is important to note that the set of SC-CO_2 estimates obtained from this analysis does not yield a probability distribution that fully characterizes uncertainty about the SC-CO_2 due to impact categories omitted from the models and sources of uncertainty that have not been fully characterized due to data limitations.

Figure I-1 presents the frequency distribution of the domestic SC-CO_2 estimates for emissions in 2030 for each discount rate. Each distribution represents 150,000 estimates based on 10,000 simulations for each combination of the three models and five socioeconomic and emissions scenarios. In general, the distributions are skewed to the right and have long right tails, which tend to be longer for lower discount rates. To highlight the difference between the impact of the discount rate on the SC-CO_2 and other quantified sources of uncertainty, the bars below the frequency distributions provide a symmetric representation of quantified variability in the SC-CO_2 estimates conditioned on each discount rate. The full set of SC-CO_2 results through 2050 is available in the docket for the ACE final rule (Docket ID EPA-HQ-OAR-2017-0355).

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[109] Specifically, the Roe and Baker (2007) distribution for the climate sensitivity parameter was bounded between 0 and 10 with a median of 3 °C and a cumulative probability between 2 and 4.5 °C of two-thirds.

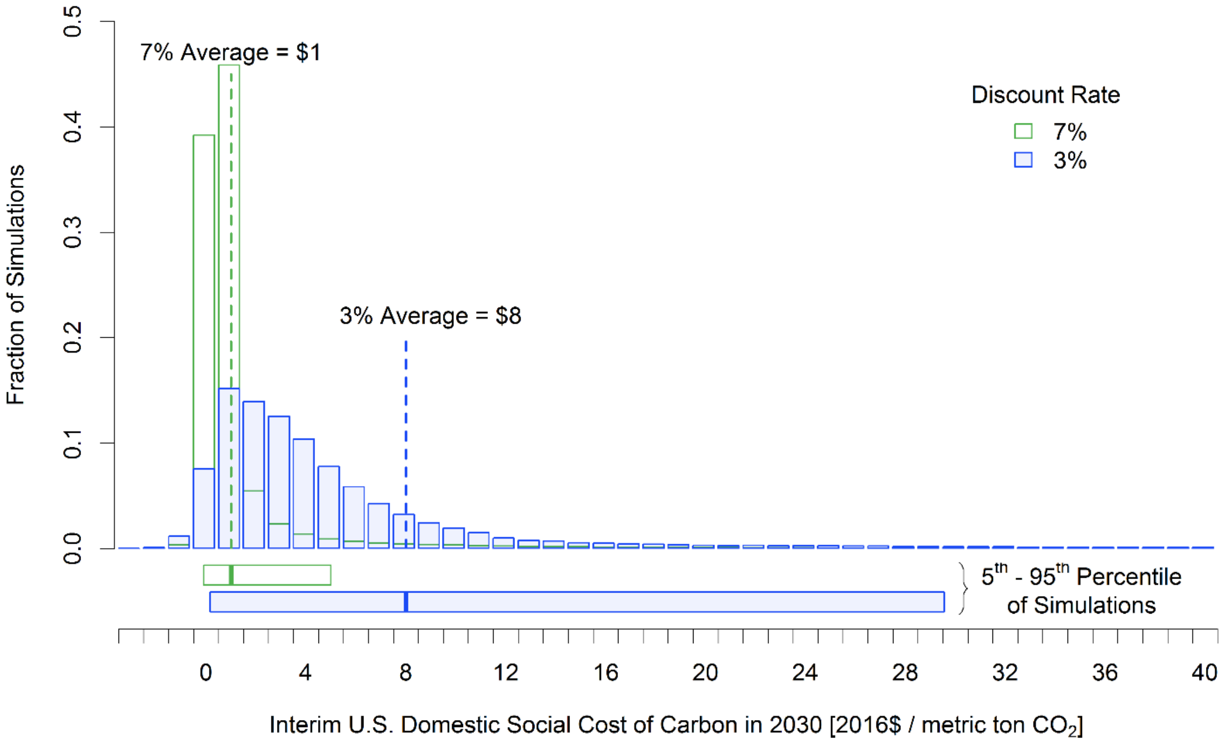

Figure I-1: Frequency Distribution of Interim Domestic SC-CO_2 Estimates for 2030 (in 2016$ per Metric Ton CO_2)

As illustrated by the frequency distributions in Figure I-1, the assumed discount rate plays a critical role in the ultimate estimate of the social cost of carbon. This is because CO_2 emissions today continue to impact society far out into the future, so with a higher discount rate, costs that accrue to future generations are weighted less, resulting in a lower estimate. Circular A-4 recommends that costs and benefits be discounted using the rates of 3 percent and 7 percent to reflect the opportunity cost of consumption and capital, respectively. Circular A-4 also recommends quantitative sensitivity analysis of key assumptions[110], and offers guidance on what sensitivity analysis can be conducted in cases where a rule will have important intergenerational benefits or costs. To account for ethical considerations of future generations and potential uncertainty in the discount rate over long time horizons, Circular A-4 suggests "further sensitivity analysis using a lower but positive discount rate in addition to calculating net benefit using discount rates of 3 and 7 percent" (page 36) and notes that research from the 1990s suggests intergenerational rates "from 1 to 3 percent per annum" (OMB, 2003). EPA considers the uncertainty in this key assumption by calculating the domestic SC-CO_2 based on a 2.5 percent discount rate, in addition to the 3 and 7 percent used in the main analysis. Using a 2.5 percent discount rate, the average domestic SC-CO_2 estimate across all the model runs for emissions occurring over 2020-2045 ranges from $10 to $14 per metric ton of CO_2 (in 2018 dollars). In this case the forgone domestic climate benefits under Option A in 2025 are $21 million; by 2035, the estimated forgone benefits decrease to $9.4 million; and by 2045, the estimated forgone benefits are $35 million.

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[110] "If benefit or cost estimates depend heavily on certain assumptions, you should make those assumptions explicit and carry out sensitivity analyses using plausible alternative assumptions." (OMB, 2003, page 42).

In addition to the approach to accounting for the quantifiable uncertainty described above, the scientific and economics literature has further explored known sources of uncertainty related to estimates of the SC-CO_2. For example, researchers have published papers that explore the sensitivity of IAMs and the resulting SC-CO_2 estimates to different assumptions embedded in the models (*e.g.*, Hope, 2013, Anthoff & Tol, 2013, and Nordhaus, 2014). However, there remain additional sources of uncertainty that have not been fully characterized and explored due to remaining data limitations. Additional research is needed in order to expand the quantification of various sources of uncertainty in estimates of the SC-CO_2 (*e.g.*, developing explicit probability distributions for more inputs pertaining to climate impacts and their valuation). On the issue of intergenerational discounting, some experts have argued that a declining discount rate would be appropriate to analyze impacts that occur far into the future (Arrow *et al.*, 2013). However, additional research and analysis is still needed to develop a methodology for implementing a declining discount rate and to understand the implications of applying these theoretical lessons in practice. The 2017 National Academies report also provides recommendations pertaining to discounting, emphasizing the need to more explicitly model the uncertainty surrounding discount rates over long time horizons, its connection to uncertainty in economic growth, and, in turn, to climate damages using a Ramsey-like formula (National Academies of Sciences & Medicine, 2017). These and other research needs are discussed in detail in the 2017 National Academies' recommendations for a comprehensive update to the current methodology, including a more robust incorporation of uncertainty.

I.3 Forgone Global Climate Benefits

In addition to requiring reporting of impacts at a domestic level, OMB Circular A-4 states that when an agency "evaluate[s] a regulation that is likely to have effects beyond the borders of the United States, these effects should be reported separately" (OMB, 2003; page 15).[111] This guidance is relevant to the valuation of damages from CO_2 and other GHGs, given that GHGs contribute to damages around the world independent of the country in which they are emitted. Therefore, this section presents the forgone global climate benefits in 2030 from this final rule using the global SC-CO_2 estimates corresponding to the model runs that generated the domestic SC-CO_2 estimates used in the main analysis. The average global SC-CO_2 estimate across all the model runs for emissions occurring over 2025-2045 range from $6 to $13 per metric ton of CO_2 emissions (in 2018 dollars) using a 7 percent discount rate, and $55 to $76 per metric ton of CO_2 emissions (in 2018 dollars) using a 3 percent discount rate. The domestic SC-CO_2 estimates presented above are approximately 18 percent and 14 percent of these global SC-CO_2 estimates for the 7 percent and 3 percent discount rates, respectively.

Applying these estimates to the forgone CO_2 emission reductions results in estimated forgone global climate benefits in 2025 of $13 million using a 7 percent discount rate and $110 million using a 3 percent discount

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[111] While Circular A-4 does not elaborate on this guidance, the basic argument for adopting a domestic only perspective for the central benefit-cost analysis of domestic policies is based on the fact that the authority to regulate only extends to a nation's own residents who have consented to adhere to the same set of rules and values for collective decision-making, as well as the assumption that most domestic policies will have negligible effects on the welfare of other countries' residents (U.S. EPA, 2010a; Kopp *et al.*, 1997; Whittington & MacRae Jr, 1986). In the context of policies that are expected to result in substantial effects outside of U.S. borders, an active literature has emerged discussing how to appropriately treat these impacts for purposes of domestic policymaking (*e.g.*, Gayer & Viscusi, 2016, 2017; Anthoff & Tol, 2010; Fraas *et al.*, 2016; Revesz *et al.*, 2017). This discourse has been primarily focused on the regulation of GHGs, for which domestic policies may result in impacts outside of U.S. borders due to the global nature of the pollutants.

rate. By 2045, the estimated forgone global climate benefits are \$33 million using a 7 percent discount rate and \$190 million using a 3 percent discount rate.

Under the sensitivity analysis considered above using a 2.5 percent discount rate, the average global SC-CO_2 estimate across all the model runs for emissions occurring over 2025-2045 ranges from \$80 to \$105 per metric ton of CO_2 (2018 dollars); in this case the forgone global climate benefits in 2025 are \$160 million; by 2045, the forgone global benefits in this sensitivity case increase to \$260 million.

J Methodology for Modeling Air Quality Changes for the Final Rule

As described in Chapter 8, EPA applied photochemical modeling to create air quality surfaces that were then used in air pollution co-benefits calculations of the final rule (*i.e.*, Option A). The photochemical modeling-based surfaces captured air pollution impacts resulting from changes in electricity generation profile due to the incremental costs to generate electricity at plants incurring water treatment costs and did not simulate the impact of emissions changes resulting from changes in energy use by steam electric power plants or resulting from changes in trucking of CCR and other waste. This appendix describes methods used to create air quality surfaces for the baseline scenario and a scenario representing water treatment technology implementation-driven EGU profile changes for Option A for 7 years: 2021, 2023, 2025, 2030, 2035, 2040 and 2045. EPA created air quality surfaces for the following pollutants and metrics: Annual average $PM_{2.5}$; May-September average of 8-hr daily maximum (MDA8) ozone; and April-October average of 1-hr daily maximum (MDA1) ozone.

The photochemical model simulations as well as the basic methodology for determining air quality changes are the same as those used in the *Regulatory Impact Analysis for the Repeal of the Clean Power Plan*, and the *Emission Guidelines for Greenhouse Gas Emissions from Existing Electric Utility Generating Units* (U.S. EPA, 2019i), also referred to the Affordable Clean Energy (ACE) rule. EPA calculated baseline and Option A scenario EGU emissions estimates of NO_x and SO_2 for all 7 years using the Integrated Planning Model (IPM) (Chapter 5 of the *RIA*; U.S. EPA, 2020d). EPA also used IPM outputs to estimate EGU emissions of $PM_{2.5}$ and PM_{10} based on emission factors described in U.S. EPA (2020a). This appendix provides an overview of the data and methods used to translate these emissions scenarios into air quality surfaces. Additional information on the air quality modeling platform (inputs and set-up), model performance evaluation for ozone and $PM_{2.5}$, emissions processing for the photochemical modeling, and additional details and numerical examples of the methodologies for developing ozone and $PM_{2.5}$ spatial fields are available in the ACE rule RIA (U.S. EPA, 2019i; see Chapter 8).

J.1 Air Quality Modeling Simulations

To create $PM_{2.5}$ and ozone spatial fields representing the baseline and Option A, EPA leveraged available photochemical modeling outputs that were created as part of the ACE rule RIA (U.S. EPA, 2019i). The full-scale modeling used in this analysis included annual model simulations for a 2011 base year and a 2023 future year to provide hourly concentrations of ozone and primary and secondarily formed $PM_{2.5}$ component species (*e.g.*, sulfate, nitrate, ammonium, elemental carbon (EC), organic aerosol (OA), and crustal material[112]) for both years nationwide. The photochemical modeling results for 2011 and 2023, in conjunction with modeling to characterize the air quality impacts from groups of emissions sources (*i.e.*, source apportionment modeling) and emissions data for the baseline and Option A, were used to construct the air quality spatial fields that reflect the influence of ELG-induced changes on ozone and $PM_{2.5}$ concentrations over the period of 2021 through 2047 (represented by IPM run years 2021 through 2045).

EPA performed the air quality model simulations (*i.e.*, model runs) using the Comprehensive Air Quality Model with Extensions (CAMx) (Ramboll Environ International Corporation, 2016). The CAMx nationwide

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[112] Crustal material refers to elements that are commonly found in the earth's crust such as Aluminum, Calcium, Iron, Magnesium, Manganese, Potassium, Silicon, Titanium and the associated oxygen atoms.

modeling domain (*i.e.*, the geographic area included in the modeling) covers all lower 48 states plus adjacent portions of Canada and Mexico using a horizontal grid resolution of 12 × 12 km shown in Figure J-1.

Figure J-1: Air Quality Modeling Domain

EPA tracked the impact of specific emissions sources on ozone and $PM_{2.5}$ in the 2023 modeled case using a tool called “source apportionment.” In general, source apportionment modeling quantifies the air quality concentrations formed from individual, user-defined groups of emissions sources or “tags”. These source tags are tracked through the transport, dispersion, chemical transformation, and deposition processes within the model to obtain hourly gridded[113] contributions from the emissions in each individual tag to hourly modeled concentrations of ozone and $PM_{2.5}$.[114] Thus, the source apportionment method provides an estimate of the effect of changes in emissions from each group of emissions sources (*i.e.*, each tag) to changes in ozone and $PM_{2.5}$ concentrations. For this analysis EPA applied outputs from source apportionment modeling for ozone and $PM_{2.5}$ using the 2023 modeled case to obtain the contributions from EGU emissions as well as other sources to ozone and to $PM_{2.5}$ component species concentrations.[115] EPA modeled ozone contributions using the Ozone Source Apportionment Technique/Anthropogenic Precursor Culpability Assessment (OSAT/APCA) tool and modeled $PM_{2.5}$ component species contributions using the Particulate Source Apportionment Technique (PSAT) tool[116]. The source apportionment modeling, which was already available from analysis performed to support the ACE rule RIA (U.S. EPA, 2019i) was used to quantify the contributions from EGU emissions on a state-by-state or, in some cases, on a multi-state basis. For ozone, EPA modeled the contributions from the 2023 EGU sector emissions of NO_X and VOC to hourly ozone concentrations for the period April through October to provide data for developing spatial fields for the two seasonal ozone benefits metrics identified above (*i.e.*, for the May-September seasonal average MDA8 ozone and the April-October seasonal average MDA1 ozone). For $PM_{2.5}$, EPA modeled the contributions from the

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[113] Hourly contribution information is provided for each grid cell to provide spatial patterns of the contributions from each tag.

[114] The sum of the contributions in a model grid cell from each tag for a pollutant equals the total concentration of that pollutant in the grid cell.

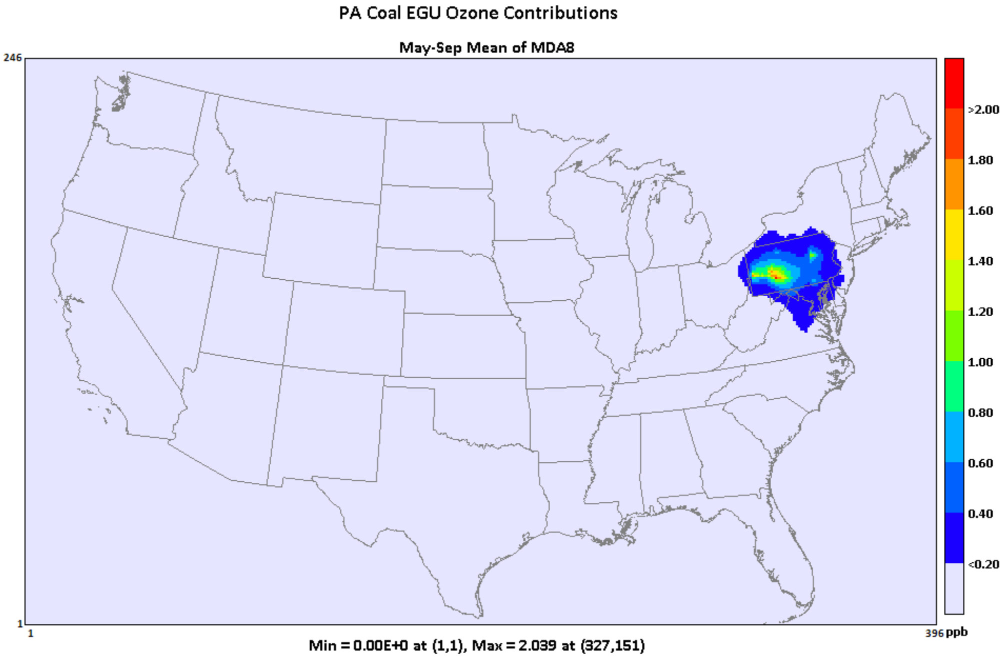
[115] In the source apportionment modeling for $PM_{2.5}$ EPA tracked the source contributions from primary, but not secondary organic aerosols (SOA). The method for treating SOA concentrations is described in U.S. EPA (2019i), Chapter 8.

[116] OSAT/APCA and PSAT tools are described in Ramboll Environ International Corporation (2016).

2023 EGU sector emissions of SO_2, NO_X, and directly emitted $PM_{2.5}$ for the entire year to inform the development of spatial fields of annual mean $PM_{2.5}$. For each state, or multi-state group, the Agency separately tagged EGU emissions depending on whether the emissions were from coal-fired units or non-coal units.[117] In addition to tagging coal-fired and non-coal EGU emissions EPA also tracked the ozone and $PM_{2.5}$ contributions from all other sources.

Examples of the magnitude and spatial extent of ozone tagged contributions are provided in Figure J-2 through Figure J-5 for coal and non-coal EGUs in Pennsylvania and Texas. These figures show how both the magnitude and the spatial patterns of contributions can differ between coal and non-coal EGU units within a state and downwind. In addition, the figures demonstrate that the spatial extent of contributions can vary substantially from state to state depending on the location of sources, the magnitude of their emissions, and meteorology. Moreover, day to day variations in meteorology can have a substantial impact on day to day patterns in contributions, which are captured in the analysis. While EPA used the daily contributions in the calculations, seasonal average contributions are presented here to provide a general illustration of the differential spatial patterns of contribution.

Figure J-2: Map of Pennsylvania Coal EGU Tag Contribution to Seasonal Average MDA8 Ozone (ppb)



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[117] For the purposes of this analysis non-coal units include natural gas, oil, biomass, municipal waste combustion and waste coal EGUs.

Figure J-3: Map of Pennsylvania Non-Coal EGU Tag Contribution to Seasonal Average MDA8 Ozone (ppb)

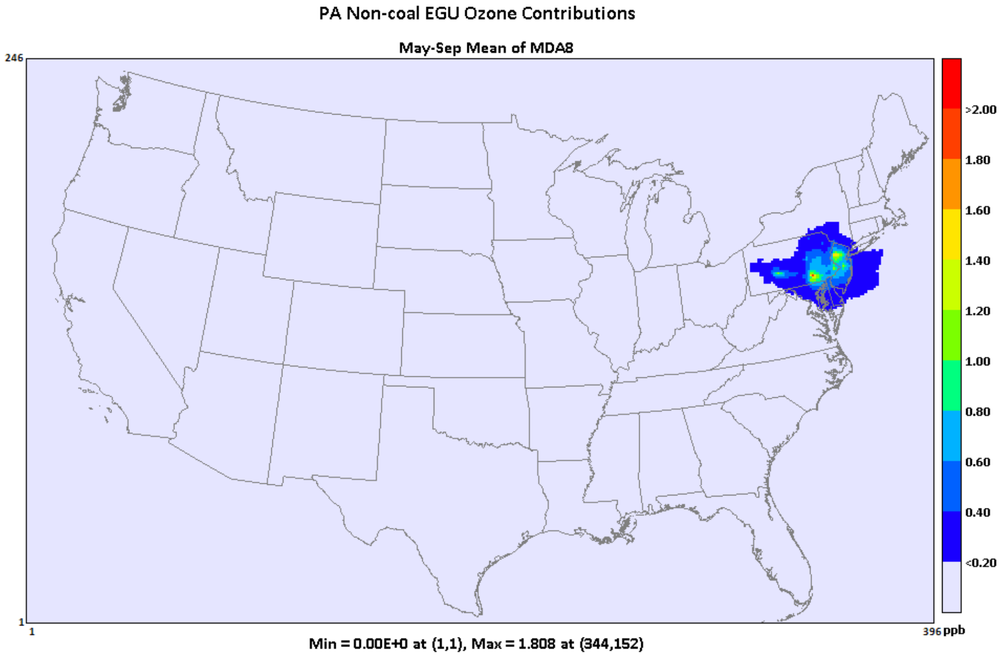


Figure J-4: Map of Texas Coal EGU Tag Contribution to Seasonal Average MDA8 Ozone (ppb)

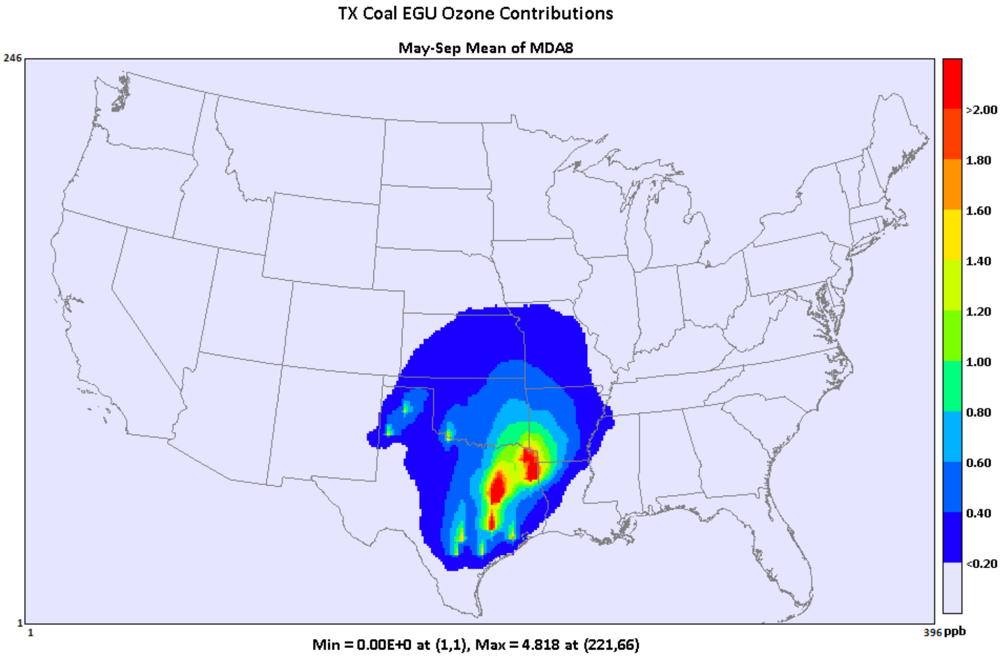
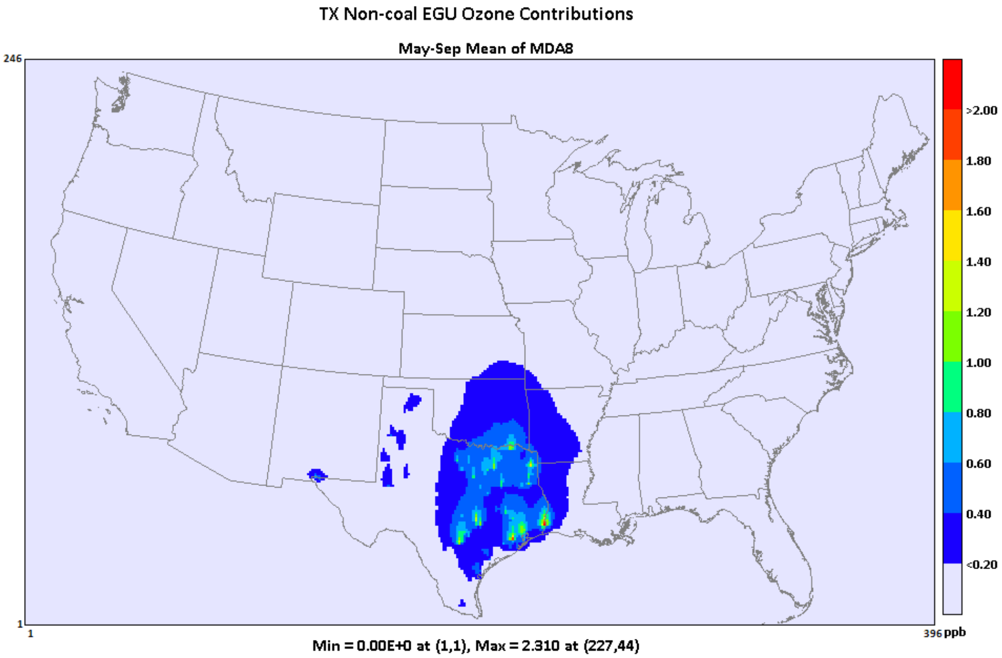


Figure J-5: Map of Texas Non-Coal EGU Tag Contribution to Seasonal Average MDA8 Ozone (ppb)



Examples of the magnitude and spatial extent of tagged contributions for $PM_{2.5}$ component species are provided in Figure J-6 through Figure J-11. Examples are provided for coal-fired EGUs in Indiana. These figures show how both the magnitude and the spatial patterns of contributions can differ by season and by $PM_{2.5}$ component species. The species which are formed through chemical reactions in the atmosphere (sulfate and nitrate) have a more regional signal than directly emitted primary $PM_{2.5}$ (OA, EC, and crustal material) whose impact is more local in nature. In addition, the chemistry and transport can vary by season with nitrate contributions being higher in the winter than in the summer and sulfate contributions being higher in the summer than in the winter.

Figure J-6: Map of Indiana Coal EGU Tag Contributions to Wintertime Average (January-March) Nitrate (µg/m^3)

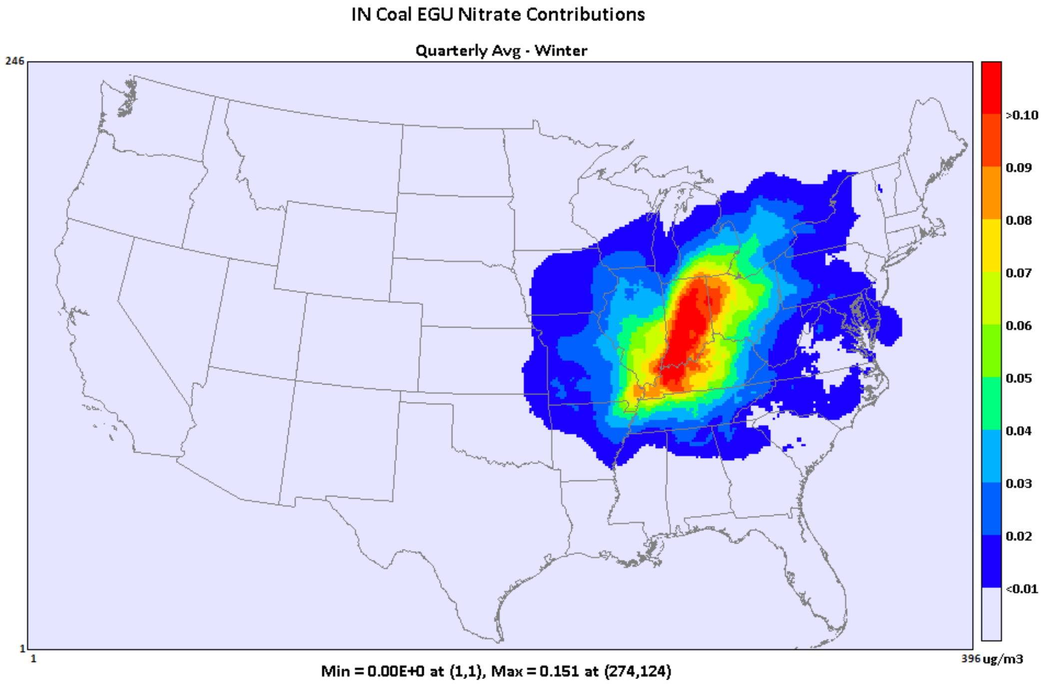


Figure J-7: Map of Indiana Coal EGU Tag Contributions to Summertime Average (July-September) Nitrate (µg/m^3)

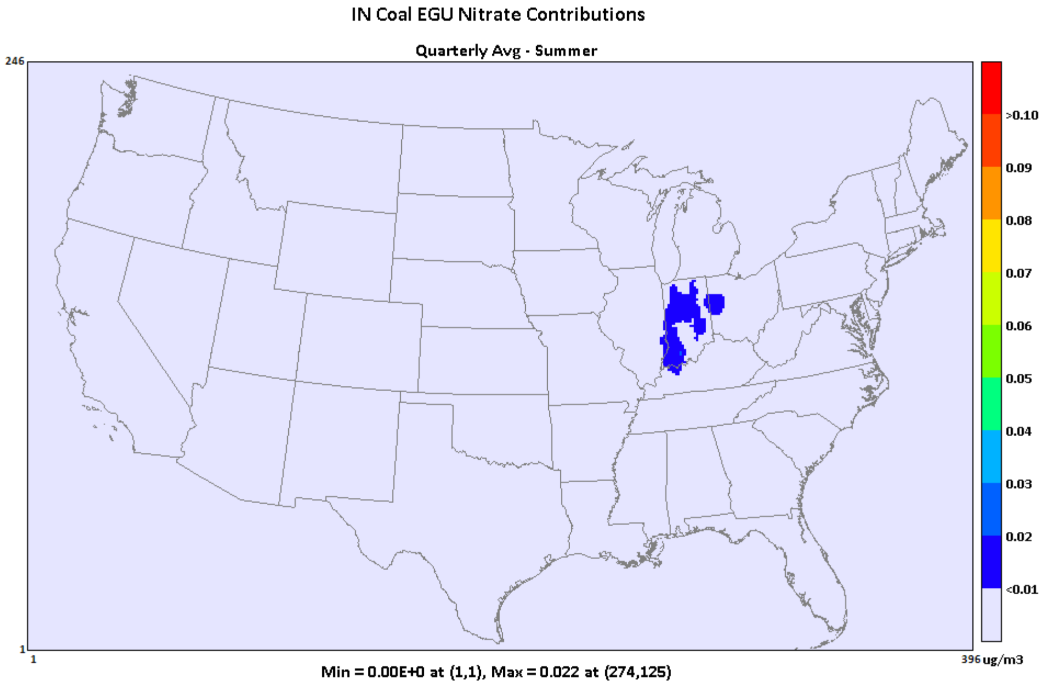


Figure J-8: Map of Indiana Coal EGU Tag Contributions to Wintertime Average (January-March) Sulfate (µg/m^3)

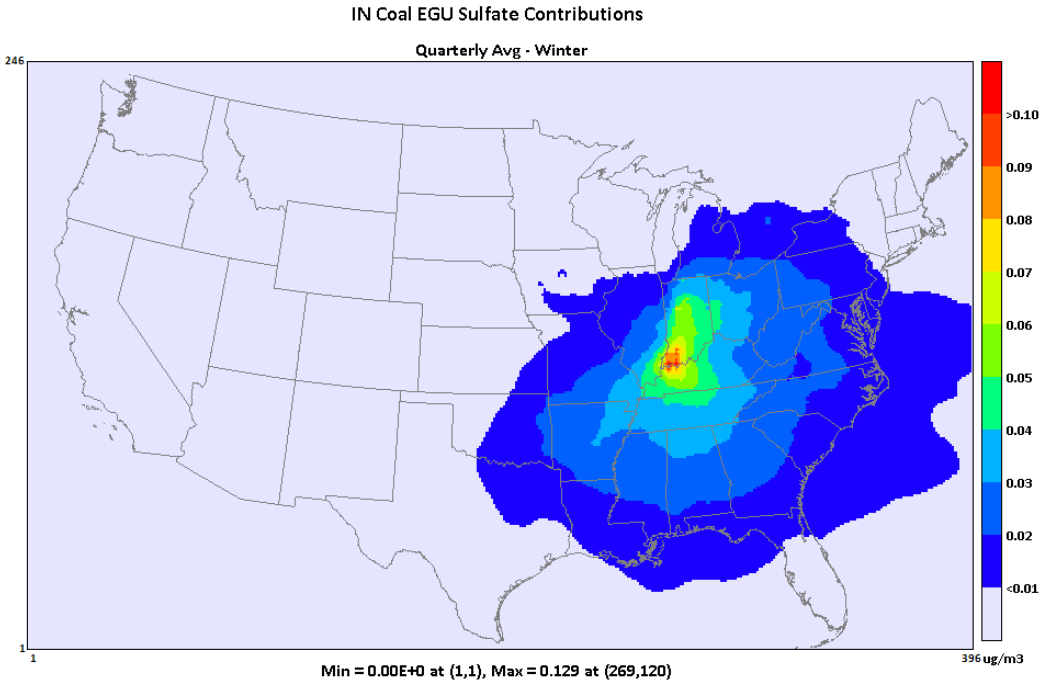


Figure J-9: Map of Indiana Coal EGU Tag Contributions to Summertime Average (July-September) Sulfate (µg/m^3)

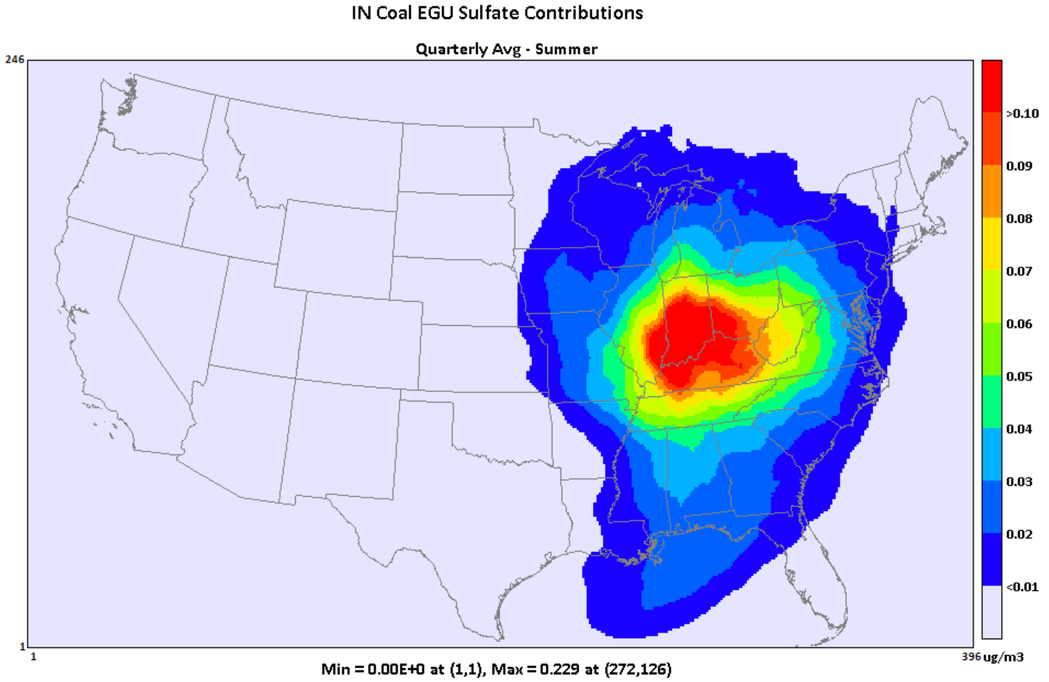


Figure J-10: Map of Indiana Coal EGU Tag Contributions to Wintertime Average (January-March) Primary $PM_{2.5}$ (µg/m^3)

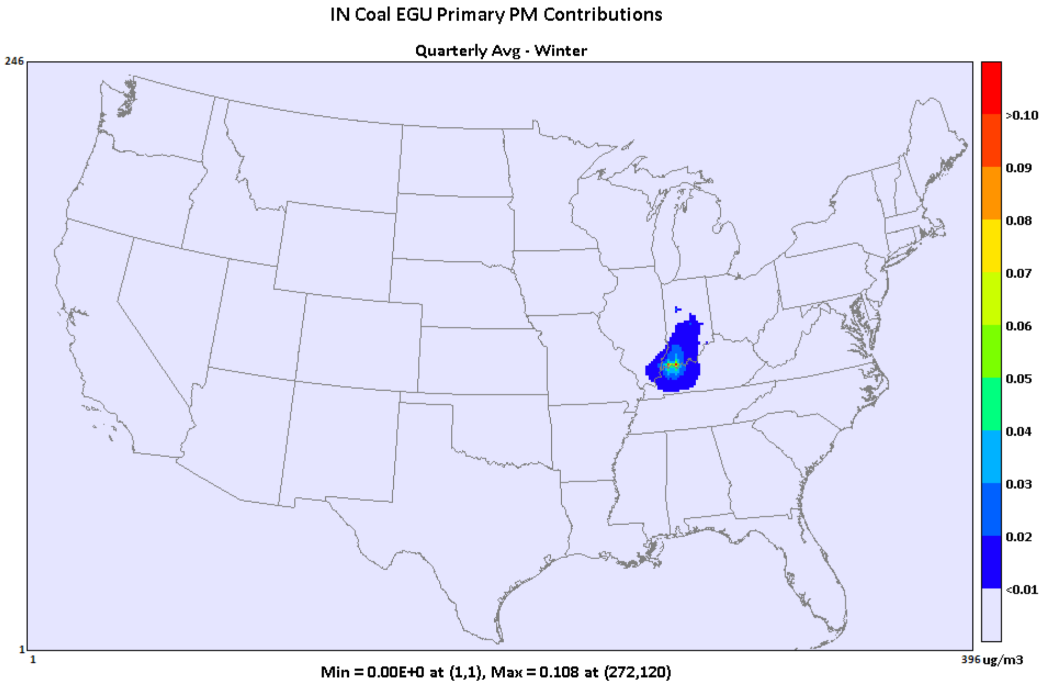
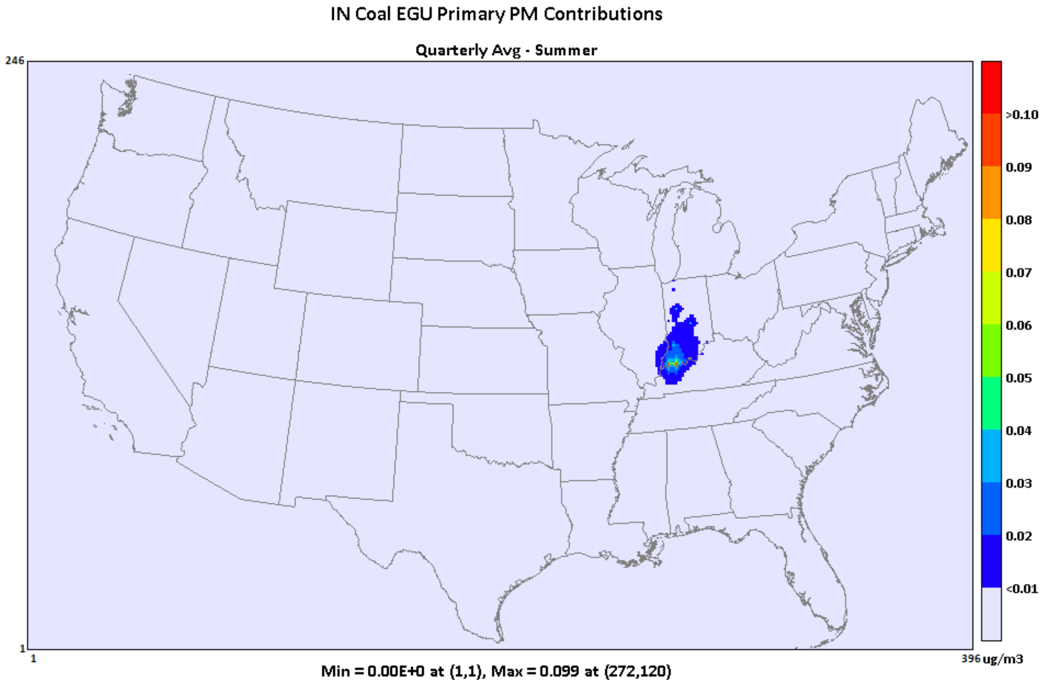


Figure J-11: Map of Indiana Coal EGU Tag Contributions to Summertime Average (July-September) Primary $PM_{2.5}$ (µg/m^3)



J.2 Applying Modeling Outputs to Create Spatial Fields

To create the air quality surfaces, EPA used the 2023 source apportion modeling outputs in combination with the endogenous IPM estimates of EGU SO_2, NO_x, and exogenously calculated $PM_{2.5}$[118] for each scenario in each of the 7 years. EGU emissions were first aggregated according to the sources associated with each tag (*i.e.*, coal and non-coal EGU emissions on a state-by-state basis). EPA scaled contributions from each "tag" based on the ratio of emissions in the year/scenario being evaluated to the emissions in the modeled 2023 scenario[119]. Scaling ratios for $PM_{2.5}$ components that are emitted directly from the source (OA, EC, crustal) were based on the relative changes in annual primary $PM_{2.5}$ emissions between the 2023 emissions case and the baseline and the Option A scenarios. Scaling ratios for components that are formed through chemical reactions in the atmosphere were created as follows: scaling ratios for sulfate were based on relative changes in annual SO_2 emissions; scaling ratios for nitrate were based on relative changes in annual NO_X emissions; and scaling ratios for ozone formed in NO_X-limited regimes[120] ("O3N") were based on relative changes in ozone season (May-September) NO_X emissions. The scaling ratios that were applied to each species and scenario are provided in Table J-1 through Table J-16. EPA held tags representing sources other than EGUs constant at 2023 levels between the baseline and Option A for all years. For each year and scenario, EPA summed the scaled contributions from all sources to create a gridded surface of total modeled O_3 or total modeled $PM_{2.5}$. Finally, the Agency created "fused" fields based on the combination of this modeled data with observed concentrations at air quality monitoring locations which were the bases for the BenMAP-CE runs. Steps in this process are described below.

EPA used the following data to create the spatial fields of ozone and $PM_{2.5}$ concentrations for the baseline and Option A scenario in each year:

1. Emissions totals used in the 2023 source apportionment modeling: 2023 annual EGU SO_2, NO_X, and directly emitted $PM_{2.5}$ emissions[121] and 2023 ozone season[122] EGU NOx emissions for each EGU tag as described in Chapter 8 of U.S. EPA (2019i);

2. 2021, 2023, 2025, 2030, 2035, 2040 and 2045 annual EGU emissions of SO_2, NO_X, and directly emitted $PM_{2.5}$ and EGU ozone season NO_X emissions for the baseline and Option A scenario that correspond to each of the EGU tags defined for the 2023 source apportionment modeling;

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[118] As described in Chapter 8, EPA estimated $PM_{2.5}$ and PM_{10} emissions by multiplying the generation predicted for each IPM plant type (ultrasupercritical coal without carbon capture and storage, combined cycle, combustion turbine, etc.) by a type-specific empirical emission factor derived from the 2016 National Emissions Inventory (NEI) and other data sources. The emission factors reflect the fuel type (including coal rank), FGD controls, and state emission limits for each plant type, where applicable. See U.S. EPA (2020a) for details.

[119] Note that while there were no EGU emissions from Washington D.C. in the 2023 source apportionment simulations, there were small emissions predicted in the baseline and Option A scenarios (<10 ton per year of NO_X and 0 tons per year of SO_2,). Since the emissions were small and there was no associated source apportionment tag to scale to, we did not include any impact of Washington D.C. EGU emissions in the air quality surfaces. We also note that changes in Washington D.C. EGU emissions between the Option A and baseline scenarios for all years were less than 1 tpy for all pollutants

[120] The CAMx model internally determines whether the ozone formation regime is NO_X-limited or VOC-limited depending on predicted ratios of indicator chemical species

[121] See footnote 118.

[122] "Ozone season NO_X emissions" refers to total NO_X (tons) emitted during the period of May-September.

3. Daily 2011 and 2023 modeling-based concentrations of 24-hour average $PM_{2.5}$ component species and MDA1 and MDA8 ozone;
4. 2023 daily contributions to 24-hour average $PM_{2.5}$ component species and MDA1 and MDA8 ozone from each of the various source tags; and
5. Base period (2011) "fused surfaces" of measured and modeled air quality[123] representing quarterly average $PM_{2.5}$ component species concentrations and ozone concentrations for the two seasonal average ozone metrics. These "fused surfaces" use the ambient data to adjust modeled fields to match observed data at locations of monitoring sites. Details on the methods for creating fused surfaces are provided in Chapter 8 of U.S. EPA (2019i).

Next, we identify the general process for developing the spatial fields for $PM_{2.5}$ using the 2025 baseline as an example to illustrate the procedure. The steps in this process are as follows:

1. Use the EGU annual SO_2, NO_X, and directly emitted $PM_{2.5}$ emissions[124] for the 2025 baseline and the corresponding modeled 2023 SO_2, NO_X, and directly emitted $PM_{2.5}$ emissions to calculate the ratio of 2025 baseline emissions to modeled 2023 emissions for each of these pollutants for each EGU tag (*i.e.*, a scaling ratio for each pollutant and each tag).
2. Multiply the tag-specific 2025 to 2023 EGU emissions-based scaling ratios from step (1) by the corresponding 365 gridded daily 24-hour average $PM_{2.5}$ component species contributions from the 2023 contribution modeling. Apply the emissions ratios for SO_2 to sulfate contributions; apply the ratios for annual NO_X to nitrate contributions; and apply the ratios for directly emitted $PM_{2.5}$ to the EGU contributions to primary OA, EC and crustal material. This step results in 365 adjusted gridded daily $PM_{2.5}$ component species contributions for each EGUs tag that reflects the emissions in the 2025 baseline.
3. For each individual $PM_{2.5}$ component species, sum the adjusted gridded contributions for each EGU tag from step (2) to produce a gridded daily EGU tag total.
4. Combine the daily total EGU contributions for each $PM_{2.5}$ component species from step (3) with the species contributions from source tags representing all other sources of $PM_{2.5}$. As part of this step also add the total secondary organic aerosol concentrations from the 2023 modeling to the net EGU contributions of primary OA. Note that the secondary organic aerosol concentration does not change between scenarios. This step results in 24-hour average $PM_{2.5}$ component species concentrations for the 2025 baseline in each model grid cell, nationwide for each day in the year.
5. For each $PM_{2.5}$ component species, average the daily concentrations from step (4) for each quarter of the year.

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[123] In this analysis, a "fused surface" represents a spatial field of concentrations of a particular pollutant that was derived by applying the Enhanced Voronoi Neighbor Averaging with adjustment using modeled and measured air quality data (*i.e.*, eVNA) technique (Ding *et al.*, 2016).

[124] The 2021, 2023, 2025, 2030, 2035, 2040 and 2045 EGU SO_2, NO_X and directly emitted $PM_{2.5}$ emissions for the baseline and Option A scenarios were obtained from IPM outputs described in Chapter 8 of this BCA and in Chapter 5 of the RIA (U.S. EPA, 2020d).

6. Divide the quarterly average $PM_{2.5}$ component species concentrations from step (5)[125] by the corresponding quarterly average species concentrations from the 2011 CAMx model run. This step provides a Relative Response Factor (*i.e.*, RRF) between 2011 and the 2025 baseline for each species in each model grid cell.

7. Multiply the species-specific quarterly RRFs from step (6) by the corresponding species-specific quarterly average concentrations from the base period (2011) fused surfaces to produce quarterly average species concentrations for the 2025 baseline.

8. Sum the 2025 baseline quarterly average species concentrations from step (7) over the species to produce total $PM_{2.5}$ concentrations for each quarter. Finally, average the total $PM_{2.5}$ concentrations for the four quarters of the year to produce the spatial field of annual average $PM_{2.5}$ concentrations for the 2025 baseline that are input to BenMAP-CE.

EPA repeated the steps above for the baseline in each of the 6 other analysis years as well as for the Option A scenario in each year.

For generating the spatial fields for each of the two ozone concentration metrics (MDA1 and MDA8), EPA followed steps similar to those above for $PM_{2.5}$. Again, we use the 2025 baseline to illustrate the steps for producing ozone spatial fields for each of the cases we analyzed.

1. Use the EGU May through September (i.e., Ozone Season - OS) NO_X for the 2025 baseline[126] and the corresponding modeled 2023 OS NO_X emissions to calculate the ratio of 2025 baseline emissions to modeled 2023 emissions for each EGU tag (*i.e.*, an ozone-season scaling factor for each tag).

2. The source apportionment modeling provided separate ozone contributions for ozone formed in VOC-limited chemical regimes (O_3V) and ozone formed in NO_X-limited chemical regimes (O_3N).[127] Multiply the tag-specific 2025 to modeled 2023 EGU NO_X emissions-based scaling ratios from step (1) by the corresponding O_3N gridded daily contributions to MDA1 and MDA8 concentrations from the 2023 contribution modeling. This step results in adjusted gridded daily MDA1 and MDA8 contributions due to NO_X changes for each EGUs tag that reflect the emissions in the 2025 baseline.

3. For MDA1 and MDA8, sum the adjusted contributions for each EGU tag from step (2) to produce a daily adjusted EGU tag total. Since IPM does not output VOC from EGUs, there are no predicted changes in VOC emissions in these scenarios so the O_3V contributions remain unchanged. The contributions from the unaltered 2023 O_3V tags are added to the summed adjusted O_3N EGU tags.

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[125] Ammonium concentrations are calculated assuming that the degree of neutralization of sulfate ions remains at 2011 levels (see Chapter 8 of U.S. EPA [2019i] for details).

[126] The 2021, 2023, 2025, 2030, 2035, 2040, 2045 and 2045 EGU NO_X emissions for the baseline and Option A scenario were obtained from IPM outputs described in Chapter 5 of the *RIA* (U.S. EPA, 2020d).

[127] Information on the treatment of ozone contributions under NOx-limited and VOC-limited chemical regimes in the CAMx APCA source apportionment technique can be found in the CAMx v6.40 User's Guide (Ramboll Environ International Corporation, 2016).

4. Combine the daily total EGU contributions for MDA1 and MDA8 from step (3) with the contributions to MDA1 and MDA8 from all other sources. This step results in MDA1 and MDA8 concentrations for the baseline 2025 scenario in each model grid cell, nationwide for each day in the ozone season.
5. For MDA1, average the daily concentrations from step (4) across all the days in the period April 1 through October 31. For MDA8, average the daily concentrations across all days in the period May 1 through September 30.
6. Divide the seasonal mean concentrations from step (5) by the corresponding seasonal mean concentrations from the 2011 CAMx model run. This step provides a Relative Response Factor (i.e., RRF) between 2011 and the 2025 baseline for MDA1 and MDA8 in each model grid cell.
7. Finally, multiply the RRFs for the seasonal mean metrics from step (6) by the corresponding seasonal mean concentrations from the base period (2011) MDA1 and MDA8 fused surfaces to produce seasonal mean concentrations for MDA1 and MDA8 for the 2025 baseline that are input to BenMAP-CE.

As with $PM_{2.5}$, EPA repeated the steps outlined for ozone for the baseline in each of the 6 other analysis years as well as for the Option A scenario in each year.

Selected maps showing changes in air quality concentrations between the Option A and the baseline are provided later in this appendix.

Scaling Ratio Applied to Source Apportionment Tags

Scaling ratios for $PM_{2.5}$ components that are emitted directly from the source (OA, EC, crustal) were based on relative changes in annual primary $PM_{2.5}$ emissions between the 2023 emissions case and the baseline or Option A. EPA created scaling ratios for components that are formed through chemical reactions in the atmosphere as follows: scaling ratios for sulfate were based on relative changes in annual SO_2 emissions; scaling ratios for nitrate were based on relative changes annual NO_X emissions; and scaling ratios for ozone formed in NO_X-limited regimes[128] ("O3N") were based on relative changes in ozone season (May-September) NO_X emissions. The scaling ratios that were applied to each tag and year are provided in separate tables by species, scenario, and EGU fuel-type in Table J-1 through Table J-16.

Table J-1: Ozone scaling factors for coal EGU tags in the Baseline scenario

	2021	2023	2025	2030	2035	2040	2045
AL	0.452	0.45	0.447	0.598	0.623	0.623	0.623
AR	0.896	1.204	1.226	1.206	0.458	0.46	0.461
AZ	1.011	1.073	0.773	0.84	0.865	0.878	0.905
CA	0.064	0.064	0.064	0	0	0	0
CO	1.048	0.771	0.759	0.667	0.667	0.667	0.661
CTRI	NA	NA	NA	NA	NA	NA	NA
DENJ	0	0	0	0	0	0	0
FL	0.555	0.62	0.567	0.618	0.844	0.756	0.756
GA	0.88	0.841	0.807	1.124	1.133	1.236	1.236
IA	1.114	1.165	1.123	1.107	1.096	1.116	1.033

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[128] The CAMx model internally determines whether the ozone formation regime is NO_X-limited or VOC-limited depending on predicted ratios of indicator chemical species.

Table J-1: Ozone scaling factors for coal EGU tags in the Baseline scenario

	2021	2023	2025	2030	2035	2040	2045
IDORWA	NA	NA	NA	NA	NA	NA	NA
IL	0.686	0.738	0.7	0.728	0.672	0.728	0.67
IN	0.925	0.864	0.851	0.863	0.825	0.821	0.735
KS	1.092	1.182	1.162	1.162	1.186	1.252	1.186
KY	0.383	0.494	0.346	0.477	0.307	0.484	0.358
LA	0.202	0.494	0.481	0.521	0.555	0.589	0.589
MD	0	0.166	0.129	0.103	0	0.168	0.16
MEMANHVT	0	0	0	0	0	0	0
MI	0.999	1.033	1.04	1.139	1.059	1.059	1.007
MN	1.204	1.279	1.262	0.86	0.527	0.558	0.494
MO	1.104	1.135	1.093	1.093	1.11	1.126	1.119
MS	0.225	0.294	0.286	0.286	0.29	0.286	0.291
MT	1.066	1.066	1.046	1.046	1.046	1.046	1.046
NC	0.957	1.091	0.936	0.781	0.434	0.488	0.45
NDSD	0.687	0.782	0.754	0.753	0.743	0.775	0.732
NE	1.325	1.137	1.122	1.122	1.122	1.122	1.122
NM	0.847	0.846	0.81	0.828	0.828	0.831	0.831
NV	4.275	6.262	0.907	0	0	0	0
NY	0	0	0	0	0	0	0
OH	1.108	1.19	1.175	1.175	0.964	0.963	0.894
OK	1.586	2.047	2.171	2.043	2.104	2.198	2.108
PA	0.231	0.25	0.247	0.185	0.14	0.14	0.14
SC	1.091	1.169	1.135	1.157	1.098	1.156	1.156
TB	0.546	0.478	0.468	0.472	0.472	0.472	0.469
TN	0.309	0.35	0.344	0.354	0.356	0.29	0.288
TX	0.978	1.026	1.009	1.074	1.132	1.057	1.059
UT	0.968	0.787	0.781	0.781	0.781	0.781	0.772
VA	0	0.062	0	0	0	0	0
WI	0.512	0.605	0.57	0.559	0.533	0.62	0.488
WV	1.214	1.098	1.06	1.078	0.926	0.911	0.846
WY	1.05	1.08	1.043	0.825	0.806	0.818	0.82

*CTRI = CT and RI; DENJ = DE and NJ; IDORWA = ID, OR, and WA; MEMAVTNH = ME, MA, VT, and NH; NDSD = ND and SD; TB = tribal lands

**NAs are shown where the modeled 2023 emissions were = 0 for any source apportionment tag

Table J-2: Ozone scaling factors for non-coal EGU tags in the Baseline scenario

	2021	2023	2025	2030	2035	2040	2045
AL	1.075	0.867	0.99	0.85	0.89	0.758	0.798
AR	0.676	0.677	0.636	0.615	0.738	0.768	0.757
AZ	0.653	0.641	0.672	0.644	0.696	0.775	0.608
CA	0.699	0.652	0.604	0.191	0.169	0.191	0.071
CO	0.399	0.517	0.56	0.79	0.805	0.805	0.553
CTRI	1.127	1.115	1.091	1.091	1.069	1.094	1.098
DENJ	0.867	1.06	1.136	1.172	1.14	1.051	0.905
FL	0.828	0.822	0.847	0.824	0.843	0.826	0.796
GA	0.711	0.68	0.74	0.717	0.752	0.789	0.822
IA	0.872	0.937	1.058	1.197	1.398	1.343	1.102
IDORWA	0.44	0.44	0.457	0.42	0.44	0.432	0.462
IL	0.672	0.782	0.813	0.93	1.011	0.874	0.796

Table J-2: Ozone scaling factors for non-coal EGU tags in the Baseline scenario

	2021	2023	2025	2030	2035	2040	2045
IN	0.837	0.916	0.972	0.996	1.188	1.23	1.329
KS	1.1	1.508	1.919	1.034	1.697	1.108	0.83
KY	1.034	1.096	1.221	1.351	1.305	1.079	1.127
LA	0.42	0.406	0.419	0.389	0.272	0.267	0.263
MD	1.066	1.069	1.075	1.114	1.077	1.088	0.988
MEMANHVT	0.6	0.596	0.597	0.58	0.571	0.565	0.566
MI	1.165	1.106	1.089	1.117	1.168	1.145	1.033
MN	0.6	0.615	0.644	0.601	0.918	0.917	0.671
MO	0.417	0.473	0.558	0.496	0.712	0.611	0.514
MS	0.367	0.32	0.38	0.384	0.332	0.31	0.32
MT	0.027	0.027	0.029	0.037	0.054	0.063	0.063
NC	0.898	0.809	0.961	1.069	0.937	0.694	0.682
NDSD	0.567	0.991	0.73	0.747	0.824	0.78	0.756
NE	0.828	0.921	0.864	0.831	0.914	0.772	0.653
NM	0.629	0.596	0.621	0.45	0.268	0.25	0.077
NV	0.748	0.728	0.721	0.72	0.738	0.955	1.795
NY	0.863	0.865	0.847	0.794	0.705	0.63	0.642
OH	1.26	1.453	1.477	1.693	1.683	1.585	1.64
OK	0.673	0.649	0.694	0.635	0.772	0.961	0.634
PA	0.986	0.976	0.949	0.908	0.919	0.866	0.711
SC	0.708	0.689	0.812	0.844	0.853	0.855	0.83
TB	0.233	0.23	0.247	0.237	0.257	0.285	0.223
TN	0.741	0.845	0.864	0.974	0.791	0.9	0.975
TX	0.924	0.909	0.908	0.82	0.804	0.819	0.423
UT	0.493	0.491	0.493	0.372	0.374	0.424	0.326
VA	0.749	0.831	0.849	1	0.922	0.832	0.759
WI	0.659	0.733	0.758	0.766	0.835	0.837	0.781
WV	0.194	0.164	0.164	0.25	0.853	0.98	1.209
WY	0.015	0.03	0.015	0.075	0.239	0.239	0.239

*CTRI = CT and RI; DENJ = DE and NJ; IDORWA = ID, OR, and WA; MEMAVTNH = ME, MA, VT, and NH; NDSD = ND and SD; TB = tribal lands

Table J-3: Ozone scaling factors for coal EGU tags in the Option A scenario

	2021	2023	2025	2030	2035	2040	2045
AL	0.452	0.45	0.447	0.598	0.623	0.623	0.623
AR	0.902	1.16	1.178	1.198	0.458	0.46	0.461
AZ	1.011	1.073	0.773	0.84	0.865	0.878	0.905
CA	0.064	0.064	0.064	0	0	0	0
CO	1.05	0.771	0.759	0.667	0.667	0.667	0.661
CTRI	NA	NA	NA	NA	NA	NA	NA
DENJ	0	0	0	0	0	0	0
FL	0.568	0.62	0.564	0.641	0.838	0.756	0.756
GA	0.88	0.841	0.817	0.951	1.03	1.063	1.063
IA	1.121	1.174	1.13	1.121	1.101	1.121	1.037
IDORWA	NA	NA	NA	NA	NA	NA	NA
IL	0.624	0.674	0.634	0.66	0.633	0.662	0.633
IN	0.937	0.879	0.864	0.879	0.826	0.821	0.732
KS	1.092	1.19	1.163	1.181	1.186	1.252	1.186
KY	0.395	0.507	0.373	0.471	0.307	0.453	0.358
LA	0.26	0.494	0.481	0.521	0.555	0.589	0.586

Table J-3: Ozone scaling factors for coal EGU tags in the Option A scenario

	2021	2023	2025	2030	2035	2040	2045
MD	0	0.158	0.129	0.099	0	0.168	0.148
MEMANHVT	0	0	0	0	0	0	0
MI	0.99	1.028	1.044	1.139	1.059	1.059	1.007
MN	1.208	1.279	1.266	0.86	0.528	0.56	0.494
MO	1.107	1.164	1.095	1.095	1.109	1.126	1.119
MS	0.237	0.294	0.286	0.286	0.286	0.281	0.291
MT	1.066	1.066	1.046	1.046	1.046	1.046	1.046
NC	0.93	1.13	0.931	0.813	0.434	0.494	0.446
NDSD	0.688	0.782	0.753	0.753	0.743	0.775	0.733
NE	1.325	1.137	1.122	1.122	1.122	1.122	1.122
NM	0.847	0.846	0.81	0.828	0.828	0.831	0.831
NV	4.281	5.911	0.907	0	0	0	0
NY	0	0	0	0	0	0	0
OH	1.108	1.19	1.175	1.175	0.966	0.963	0.894
OK	1.584	2.032	2.188	2.04	2.104	2.198	2.108
PA	0.277	0.316	0.294	0.185	0.14	0.14	0.134
SC	1.091	1.145	1.14	1.14	1.103	1.156	1.156
TB	0.546	0.478	0.468	0.472	0.472	0.472	0.469
TN	0.236	0.24	0.235	0.52	0.52	0.585	0.562
TX	0.977	1.026	1.017	1.075	1.132	1.057	1.059
UT	0.968	0.787	0.781	0.781	0.781	0.781	0.772
VA	0	0.076	0	0	0	0	0
WI	0.51	0.609	0.567	0.557	0.528	0.622	0.487
WV	1.199	1.098	1.078	1.078	0.928	0.915	0.846
WY	1.042	1.081	1.05	0.825	0.806	0.818	0.821

*CTRI = CT and RI; DENJ = DE and NJ; IDORWA = ID, OR, and WA; MEMAVTNH = ME, MA, VT, and NH; NDSD = ND and SD; TB = tribal lands

**NAs are shown where the modeled 2023 emissions were = 0 for any source apportionment tag

Table J-4: Ozone scaling factors for non-coal EGU tags in the Option A scenario

	2021	2023	2025	2030	2035	2040	2045
AL	1.077	0.864	1.008	0.936	0.967	0.753	0.801
AR	0.676	0.681	0.638	0.615	0.735	0.77	0.75
AZ	0.659	0.64	0.673	0.645	0.696	0.775	0.61
CA	0.699	0.651	0.6	0.191	0.168	0.188	0.071
CO	0.357	0.513	0.584	0.79	0.805	0.81	0.566
CTRI	1.126	1.114	1.09	1.095	1.07	1.096	1.095
DENJ	0.865	1.056	1.124	1.186	1.133	1.05	0.897
FL	0.825	0.822	0.847	0.826	0.844	0.827	0.792
GA	0.725	0.677	0.802	0.787	0.833	0.821	0.841
IA	0.835	0.941	1.084	1.162	1.391	1.343	1.104
IDORWA	0.44	0.44	0.46	0.42	0.44	0.432	0.465
IL	0.676	0.797	0.818	0.923	0.997	0.872	0.802
IN	0.836	0.958	1.007	0.994	1.171	1.249	1.342
KS	1.1	1.536	1.963	1.031	1.694	1.132	0.831
KY	1.051	1.095	1.21	1.329	1.271	1.057	1.109
LA	0.42	0.407	0.423	0.389	0.274	0.271	0.265
MD	1.065	1.069	1.074	1.115	1.076	1.088	0.992
MEMANHVT	0.598	0.594	0.595	0.579	0.57	0.563	0.565

Table J-4: Ozone scaling factors for non-coal EGU tags in the Option A scenario

	2021	2023	2025	2030	2035	2040	2045
MI	1.174	1.092	1.097	1.128	1.166	1.145	1.046
MN	0.602	0.617	0.65	0.601	0.891	0.916	0.638
MO	0.421	0.488	0.549	0.5	0.683	0.595	0.517
MS	0.366	0.325	0.365	0.37	0.333	0.307	0.313
MT	0.027	0.029	0.029	0.037	0.054	0.063	0.063
NC	0.899	0.811	0.976	1.082	0.937	0.698	0.677
NDSD	0.568	0.949	0.721	0.73	0.824	0.785	0.78
NE	0.837	0.92	0.876	0.833	0.926	0.773	0.627
NM	0.629	0.596	0.621	0.435	0.268	0.25	0.077
NV	0.748	0.729	0.72	0.72	0.738	0.954	1.873
NY	0.864	0.863	0.844	0.791	0.704	0.628	0.643
OH	1.261	1.456	1.478	1.701	1.684	1.588	1.605
OK	0.694	0.654	0.697	0.634	0.775	0.952	0.644
PA	0.986	0.976	0.949	0.91	0.92	0.868	0.712
SC	0.708	0.69	0.814	0.844	0.851	0.848	0.824
TB	0.235	0.228	0.247	0.237	0.257	0.285	0.225
TN	0.742	1.009	1.135	0.707	0.733	0.799	0.906
TX	0.921	0.906	0.905	0.82	0.807	0.817	0.428
UT	0.492	0.491	0.492	0.373	0.374	0.426	0.328
VA	0.749	0.833	0.848	1.012	0.921	0.83	0.758
WI	0.66	0.739	0.756	0.764	0.838	0.836	0.774
WV	0.194	0.164	0.164	0.258	0.836	0.965	1.21
WY	0.015	0.03	0.015	0.075	0.239	0.239	0.239

*CTRI = CT and RI; DENJ = DE and NJ; IDORWA = ID, OR, and WA; MEMAVTNH = ME, MA, VT, and NH; NDSD = ND and SD; TB = tribal lands

Table J-5: Nitrate scaling factors for coal EGU tags in the Baseline scenario

	2021	2023	2025	2030	2035	2040	2045
AL	0.33	0.327	0.346	0.416	0.355	0.382	0.384
AR	0.782	1.045	1.19	1.062	0.333	0.336	0.34
AZ	1.031	1.039	0.765	0.637	0.609	0.615	0.627
CA	0.075	0.056	0.075	0	0	0	0
CO	1.022	0.752	0.741	0.651	0.622	0.64	0.571
CTRI	0	0	0	0	0	0	0
DENJ	0	0	0	0	0	0	0
FL	0.367	0.421	0.42	0.391	0.483	0.446	0.439
GA	0.563	0.47	0.481	0.59	0.503	0.537	0.544
IA	1.236	1.273	1.256	1.231	1.126	1.128	1.046
IDORWA	NA	NA	NA	NA	NA	NA	NA
IL	0.662	0.71	0.69	0.71	0.665	0.686	0.609
IN	0.804	0.753	0.741	0.744	0.701	0.679	0.559
KS	1.034	1.119	1.197	1.029	0.894	0.969	0.895
KY	0.274	0.339	0.27	0.326	0.198	0.27	0.22
LA	0.137	0.365	0.371	0.392	0.401	0.396	0.396
MD	0.017	0.117	0.099	0.085	0	0.277	0.218
MEMANHVT	0	0	0	0	0	0	0
MI	0.947	1.059	1.133	1.178	0.961	0.956	0.9
MN	1.166	1.258	1.274	0.836	0.457	0.486	0.425
MO	1.034	1.153	1.129	1.056	1.003	0.964	0.826
MS	0.181	0.217	0.229	0.232	0.231	0.229	0.232

Table J-5: Nitrate scaling factors for coal EGU tags in the Baseline scenario

	2021	2023	2025	2030	2035	2040	2045
MT	0.951	0.951	0.934	0.934	0.934	0.934	0.934
NC	0.864	0.919	0.856	0.69	0.362	0.387	0.369
NDSD	0.668	0.736	0.716	0.686	0.668	0.685	0.641
NE	1.313	1.128	1.116	1.076	1.042	1.044	0.958
NM	0.764	0.764	0.751	0.646	0.517	0.497	0.487
NV	4.959	7.095	1.354	0.379	0.379	0.379	0.379
NY	0	0	0	0	0	0	0
OH	1.149	1.212	1.194	1.126	0.789	0.696	0.664
OK	1.248	1.702	1.887	1.358	1.348	1.518	1.373
PA	0.2	0.227	0.213	0.139	0.104	0.104	0.104
SC	1.123	1.177	1.168	1.096	0.833	0.864	0.87
TB	0.534	0.466	0.461	0.431	0.374	0.358	0.348
TN	0.265	0.322	0.341	0.308	0.293	0.237	0.232
TX	0.925	1.002	1.056	0.942	0.859	0.837	0.768
UT	0.929	0.755	0.749	0.733	0.661	0.632	0.61
VA	0	0.053	0.025	0	0	0	0
WI	0.577	0.698	0.691	0.59	0.537	0.592	0.429
WV	1.065	0.951	0.922	0.883	0.598	0.575	0.548
WY	1.054	1.069	1.049	0.813	0.803	0.81	0.813

*CTRI = CT and RI; DENJ = DE and NJ; IDORWA = ID, OR, and WA; MEMAVTNH = ME, MA, VT, and NH; NDSD = ND and SD; TB = tribal lands

**NAs are shown where the modeled 2023 emissions were = 0 for any source apportionment tag

Table J-6: Nitrate scaling factors for non-coal EGU tags in the Baseline scenario

	2021	2023	2025	2030	2035	2040	2045
AL	0.7224	0.6346	0.6822	0.7176	0.9528	0.8221	0.7229
AR	0.7654	0.7854	0.767	0.8019	0.9865	0.9689	0.9278
AZ	0.7901	0.7752	0.8465	0.8106	0.8798	0.9989	0.77
CA	0.8245	0.7756	0.6872	0.2187	0.2076	0.2176	0.1133
CO	0.2743	0.3995	0.4415	0.603	0.701	0.7478	0.5169
CTRI	1.1378	1.124	1.12	1.0821	1.0644	1.0694	1.0842
DENJ	1.0132	1.237	1.2665	1.3849	1.3657	1.2833	1.11
FL	0.8984	0.8967	0.9006	0.8825	0.9184	0.8994	0.874
GA	0.7836	0.7636	0.7948	0.8473	0.9811	0.938	0.9916
IA	0.7402	0.7961	0.8476	0.9896	1.1419	1.091	0.8687
IDORWA	0.5435	0.5398	0.5472	0.525	0.5335	0.5394	0.5588
IL	0.6181	0.6802	0.6277	0.8198	0.8734	0.7982	0.7158
IN	0.7144	0.771	0.7711	0.8556	1.0969	1.1166	1.2091
KS	0.8034	1.0743	1.3381	0.7854	1.231	0.8555	0.6366
KY	0.9515	1.0506	1.1487	1.4607	1.5971	1.4229	1.4767
LA	0.4008	0.397	0.3835	0.3561	0.3372	0.3078	0.3018
MD	1.1702	1.1933	1.1979	1.2382	1.2598	1.3143	1.2545
MEMANHVT	0.5943	0.591	0.5913	0.5717	0.5658	0.5649	0.5674
MI	1.1477	1.0598	1.0409	1.1511	1.159	1.1482	1.0307
MN	0.5391	0.5517	0.5458	0.5466	0.7045	0.7024	0.5426
MO	0.3655	0.408	0.4727	0.4538	0.7392	0.713	0.4788
MS	0.3945	0.3668	0.4028	0.4206	0.4611	0.4151	0.4187
MT	0.01	0.01	0.0108	0.0141	0.0204	0.0243	0.0243
NC	0.7542	0.7324	0.792	0.8889	0.8718	0.6818	0.662

Table J-6: Nitrate scaling factors for non-coal EGU tags in the Baseline scenario

	2021	2023	2025	2030	2035	2040	2045
NDSD	0.3605	0.6096	0.4619	0.4461	0.594	0.57	0.4937
NE	0.7964	0.8836	0.8376	0.7995	0.8713	0.7625	0.6677
NM	0.5007	0.4876	0.4876	0.2455	0.1917	0.1864	0.0901
NV	0.9766	0.9659	0.9386	1.0079	1.0579	1.0764	1.5046
NY	0.9176	0.9231	0.9129	0.8708	0.7774	0.6904	0.694
OH	1.2905	1.4225	1.4123	1.7681	1.7036	1.7142	1.8185
OK	0.5194	0.497	0.5215	0.5286	0.7589	0.8601	0.6078
PA	0.9857	1.1102	1.1479	1.1538	1.2547	1.1082	0.9329
SC	0.6111	0.6119	0.6653	0.7243	0.8134	0.7929	0.7828
TB	0.0961	0.0951	0.103	0.099	0.1079	0.1218	0.0941
TN	0.8409	0.932	0.9587	1.1883	1.1385	1.1608	1.2251
TX	0.8789	0.8367	0.8084	0.7709	0.8254	0.8342	0.4252
UT	0.6888	0.7056	0.7072	0.6535	0.6868	0.7293	0.6833
VA	0.8064	0.8795	0.8669	1.0732	1.0763	0.9804	0.8838
WI	0.7513	0.7947	0.8048	0.8195	0.8917	0.8716	0.8293
WV	0.1123	0.1126	0.1229	0.2284	0.8747	1.0451	1.2785
WY	0.0097	0.0194	0.0097	0.0485	0.1747	0.1942	0.1942

*CTRI = CT and RI; DENJ = DE and NJ; IDORWA = ID, OR, and WA; MEMAVTNH = ME, MA, VT, and NH; NDSD = ND and SD; TB = tribal lands

Table J-7: Nitrate scaling factors for coal EGU tags in the Option A scenario

	2021	2023	2025	2030	2035	2040	2045
AL	0.328	0.327	0.347	0.416	0.355	0.382	0.384
AR	0.775	1.01	1.156	1.06	0.334	0.336	0.339
AZ	1.031	1.039	0.765	0.637	0.609	0.615	0.627
CA	0.075	0.056	0.075	0	0	0	0
CO	1.023	0.752	0.741	0.651	0.622	0.64	0.574
CTRI	0	0	0	0	0	0	0
DENJ	0	0	0	0	0	0	0
FL	0.373	0.421	0.415	0.402	0.48	0.446	0.437
GA	0.563	0.47	0.488	0.534	0.467	0.481	0.488
IA	1.24	1.313	1.26	1.239	1.129	1.13	1.05
IDORWA	NA	NA	NA	NA	NA	NA	NA
IL	0.622	0.667	0.647	0.654	0.624	0.628	0.567
IN	0.811	0.761	0.749	0.752	0.701	0.678	0.561
KS	1.034	1.134	1.205	1.038	0.897	0.976	0.899
KY	0.282	0.349	0.283	0.319	0.195	0.251	0.21
LA	0.168	0.376	0.372	0.392	0.401	0.396	0.394
MD	0.016	0.114	0.101	0.084	0	0.242	0.213
MEMANHVT	0.138	0.138	0.136	0.136	0.136	0.136	0.136
MI	0.945	1.078	1.137	1.179	0.961	0.956	0.901
MN	1.168	1.265	1.276	0.836	0.458	0.489	0.425
MO	1.038	1.163	1.123	1.056	1.005	0.964	0.827
MS	0.187	0.218	0.229	0.232	0.229	0.227	0.232
MT	0.951	0.951	0.934	0.934	0.934	0.934	0.934
NC	0.836	0.955	0.863	0.725	0.363	0.39	0.367
NDSD	0.669	0.737	0.715	0.687	0.669	0.685	0.641
NE	1.313	1.13	1.116	1.076	1.042	1.044	0.958
NM	0.764	0.764	0.751	0.646	0.517	0.493	0.487

Table J-7: Nitrate scaling factors for coal EGU tags in the Option A scenario

	2021	2023	2025	2030	2035	2040	2045
NV	4.968	6.918	1.354	0.379	0.379	0.379	0.379
NY	0	0	0	0	0	0	0
OH	1.145	1.212	1.194	1.133	0.79	0.695	0.664
OK	1.247	1.694	1.894	1.429	1.348	1.518	1.373
PA	0.243	0.288	0.267	0.139	0.104	0.104	0.101
SC	1.123	1.167	1.187	1.088	0.835	0.868	0.87
TB	0.534	0.466	0.461	0.431	0.374	0.357	0.347
TN	0.207	0.258	0.258	0.441	0.392	0.462	0.435
TX	0.924	1.002	1.06	0.942	0.859	0.837	0.77
UT	0.929	0.755	0.749	0.733	0.661	0.632	0.61
VA	0	0.06	0.025	0	0	0	0
WI	0.578	0.698	0.688	0.581	0.531	0.59	0.422
WV	1.059	0.949	0.929	0.884	0.598	0.576	0.548
WY	1.051	1.069	1.052	0.812	0.803	0.81	0.814

*CTRI = CT and RI; DENJ = DE and NJ; IDORWA = ID, OR, and WA; MEMAVTNH = ME, MA, VT, and NH; NDSD = ND and SD; TB = tribal lands

**NAs are shown where the modeled 2023 emissions were = 0 for any source apportionment tag

Table J-8: Nitrate scaling factors for non-coal EGU tags in the Option A scenario

	2021	2023	2025	2030	2035	2040	2045
AL	0.7229	0.6326	0.688	0.7548	0.9913	0.7505	0.7201
AR	0.7707	0.7899	0.7697	0.793	0.9863	0.9613	0.9235
AZ	0.7931	0.7746	0.8488	0.8123	0.8808	0.9998	0.7765
CA	0.8249	0.7752	0.6859	0.2187	0.2074	0.2165	0.1132
CO	0.26	0.3976	0.4516	0.6074	0.7014	0.7585	0.5277
CTRI	1.1373	1.1214	1.1158	1.0835	1.0646	1.0692	1.0823
DENJ	1.01	1.235	1.2612	1.3888	1.3567	1.2741	1.101
FL	0.8976	0.8967	0.8991	0.8858	0.92	0.899	0.8724
GA	0.7925	0.7622	0.8338	0.8801	1.0247	0.9582	1.0017
IA	0.7243	0.7994	0.8803	0.9743	1.1414	1.0963	0.8642
IDORWA	0.5429	0.5399	0.5485	0.5249	0.5335	0.5394	0.5603
IL	0.6219	0.683	0.6265	0.814	0.8624	0.7979	0.7192
IN	0.7122	0.7856	0.7868	0.8562	1.0957	1.1342	1.2296
KS	0.8032	1.0913	1.3659	0.7879	1.2289	0.8709	0.6373
KY	0.9623	1.0544	1.1487	1.4547	1.584	1.4376	1.4714
LA	0.4009	0.3984	0.3877	0.3542	0.3355	0.311	0.3042
MD	1.1695	1.1917	1.1853	1.2386	1.2601	1.3162	1.2558
MEMANHVT	0.593	0.5889	0.5902	0.5714	0.565	0.5636	0.5663
MI	1.1478	1.0492	1.0452	1.1571	1.1582	1.1477	1.0456
MN	0.54	0.5525	0.5486	0.5467	0.6929	0.7019	0.5282
MO	0.3667	0.4157	0.4649	0.4564	0.7222	0.6816	0.505
MS	0.3949	0.3696	0.3956	0.412	0.4526	0.3927	0.4214
MT	0.01	0.0108	0.0108	0.0141	0.0203	0.0234	0.0243
NC	0.7549	0.7351	0.7929	0.8933	0.8788	0.6797	0.66
NDSD	0.3607	0.5851	0.4569	0.4363	0.594	0.5713	0.5077
NE	0.8042	0.8829	0.8473	0.8006	0.8812	0.7633	0.646
NM	0.5007	0.4876	0.4877	0.2394	0.1917	0.1863	0.09
NV	0.9763	0.9644	0.9559	1.0081	1.0578	1.0762	1.5421
NY	0.9169	0.9199	0.9087	0.8676	0.7749	0.689	0.6939

Table J-8: Nitrate scaling factors for non-coal EGU tags in the Option A scenario

	2021	2023	2025	2030	2035	2040	2045
OH	1.2905	1.4176	1.4124	1.7761	1.7048	1.7186	1.8026
OK	0.5331	0.5009	0.5235	0.5261	0.7615	0.8593	0.6141
PA	0.9841	1.1048	1.1474	1.1403	1.2561	1.1171	0.9433
SC	0.6111	0.6131	0.663	0.7204	0.8114	0.79	0.78
TB	0.097	0.0941	0.103	0.099	0.1069	0.1218	0.0951
TN	0.8413	1.0311	1.1143	0.9858	1.0961	1.0665	1.173
TX	0.8761	0.8343	0.8055	0.7701	0.8271	0.8335	0.4296
UT	0.6849	0.705	0.7071	0.6543	0.6865	0.7302	0.6848
VA	0.8058	0.8795	0.8641	1.0783	1.079	0.9742	0.883
WI	0.7518	0.7978	0.8045	0.8197	0.8931	0.8722	0.8247
WV	0.1123	0.1126	0.1227	0.2334	0.8569	1.0288	1.2799
WY	0.0097	0.0194	0.0097	0.0485	0.1747	0.1942	0.1942

*CTRI = CT and RI; DENJ = DE and NJ; IDORWA = ID, OR, and WA; MEMAVTNH = ME, MA, VT, and NH; NDSD = ND and SD; TB = tribal lands

Table J-9: Sulfate scaling factors for coal EGU tags in the Baseline scenario

	2021	2023	2025	2030	2035	2040	2045
AL	0.568	0.604	0.61	0.695	0.601	0.616	0.622
AR	0.985	1.424	1.65	1.392	0.137	0.139	0.143
AZ	1.698	1.71	1.469	1.385	1.336	1.342	1.353
CA	0.631	0.471	0.631	0	0	0	0
CO	0.878	0.781	0.77	0.718	0.693	0.708	0.627
CTRI	0	0	0	0	0	0	0
DENJ	0	0	0	0	0	0	0
FL	0.425	0.548	0.566	0.416	0.638	0.542	0.53
GA	0.788	0.634	0.7	0.644	0.549	0.588	0.596
IA	0.641	0.48	0.469	0.454	0.431	0.434	0.39
IDORWA	NA	NA	NA	NA	NA	NA	NA
IL	0.515	0.538	0.532	0.538	0.514	0.519	0.467
IN	0.88	0.864	0.853	0.836	0.778	0.75	0.605
KS	0.885	0.962	0.997	0.883	0.739	0.822	0.735
KY	0.172	0.194	0.173	0.181	0.14	0.173	0.162
LA	0.199	0.423	0.426	0.443	0.443	0.419	0.419
MD	0.013	0.087	0.074	0.064	0	0.119	0.104
MEMANHVT	0	0	0	0	0	0	0
MI	0.65	0.569	0.847	0.892	0.665	0.663	0.619
MN	0.955	0.887	1.172	1.158	0.528	0.543	0.514
MO	1.172	1.254	1.229	1.283	1.324	1.213	1.208
MS	0.509	0.61	0.645	0.652	0.651	0.645	0.652
MT	0.525	0.525	0.515	0.599	0.599	0.599	0.599
NC	0.535	0.565	0.549	0.435	0.296	0.347	0.33
NDSD	0.58	0.597	0.581	0.574	0.571	0.579	0.553
NE	1.034	0.978	0.97	0.94	0.922	0.924	0.866
NM	1.213	1.214	1.205	1.096	1.016	0.929	0.923
NV	12.171	17.44	2.322	0.649	0.649	0.649	0.649
NY	0	0	0	0	0	0	0
OH	0.641	0.698	0.695	0.741	0.494	0.422	0.379
OK	0.831	1.177	1.225	0.842	0.791	0.872	0.798
PA	0.08	0.096	0.086	0.061	0.048	0.048	0.048

Table J-9: Sulfate scaling factors for coal EGU tags in the Baseline scenario

	2021	2023	2025	2030	2035	2040	2045
SC	1.478	1.627	1.616	1.462	1.051	1.099	1.106
TB	1.056	1.056	1.05	0.962	0.906	0.836	0.817
TN	0.285	0.347	0.366	0.257	0.224	0.242	0.243
TX	0.793	0.914	0.931	0.8	0.747	0.728	0.622
UT	1.347	1.347	1.357	1.318	1.408	1.388	1.205
VA	0	0.044	0.021	0	0	0	0
WI	0.515	0.659	0.652	0.512	0.463	0.511	0.396
WV	1.387	0.864	0.838	0.814	0.518	0.509	0.471
WY	0.734	0.784	0.776	0.52	0.511	0.517	0.599

*CTRI = CT and RI; DENJ = DE and NJ; IDORWA = ID, OR, and WA; MEMAVTNH = ME, MA, VT, and NH; NDSD = ND and SD; TB = tribal lands

**NAs are shown where the modeled 2023 emissions were = 0 for any source apportionment tag

Table J-10: Sulfate scaling factors for non-coal EGU tags in the Baseline scenario

	2021	2023	2025	2030	2035	2040	2045
AL	0.00	0.00	0.00	0.00	0.00	0.00	0.00
AR	0.00	0.00	0.00	0.00	0.00	0.00	0.00
AZ	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CA	0.17	0.17	0.21	0.00	0.00	0.01	0.01
CO	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CTRI	2.00	2.00	2.00	2.00	2.00	2.00	2.00
DENJ	2.50	2.50	2.50	2.50	2.50	2.50	2.50
FL	0.68	0.68	0.68	0.67	0.67	0.67	0.67
GA	0.04	0.09	0.10	0.10	0.28	0.32	0.31
IA	0.00	0.00	0.00	0.00	0.00	0.00	0.00
IDORWA	0.07	0.07	0.07	0.07	0.07	0.07	0.07
IL	0.00	0.00	0.00	0.00	0.00	0.00	0.00
IN	0.20	0.20	0.20	0.20	0.20	0.20	0.20
KS	0.00	0.00	0.00	0.00	0.00	0.00	0.00
KY	0.03	0.03	0.03	0.03	0.02	0.02	0.02
LA	0.06	0.06	0.06	0.06	0.06	0.06	0.06
MD	0.45	0.45	0.45	0.45	0.45	0.45	0.45
MEMANHVT	0.31	0.31	0.31	0.31	0.31	0.31	0.31
MI	0.26	0.07	0.07	0.06	0.06	0.06	0.06
MN	0.29	0.29	0.29	0.29	0.29	0.29	0.29
MO	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MS	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MT	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NC	0.01	0.01	0.01	0.01	0.00	0.00	0.00
NDSD	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NE	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NM	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NV	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NY	1.90	1.90	1.90	0.64	0.64	0.64	0.64
OH	0.08	0.08	0.08	0.08	0.08	0.08	0.08
OK	0.00	0.00	0.00	0.00	0.00	0.00	0.00
PA	0.04	0.04	0.04	0.04	0.04	0.04	0.04
SC	0.01	0.01	0.01	0.01	0.00	0.00	0.00
TB	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table J-10: Sulfate scaling factors for non-coal EGU tags in the Baseline scenario

	2021	2023	2025	2030	2035	2040	2045
TN	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TX	0.04	0.04	0.04	0.04	0.04	0.04	0.04
UT	0.00	0.00	0.00	0.00	0.00	0.00	0.00
VA	0.20	0.21	0.20	0.20	0.20	0.20	0.20
WI	0.00	0.00	0.00	0.00	0.00	0.00	0.00
WV	0.00	0.00	0.00	0.00	0.00	0.00	0.00
WY	0.00	0.00	0.00	0.00	0.00	0.00	0.00

*CTRI = CT and RI; DENJ = DE and NJ; IDORWA = ID, OR, and WA; MEMAVTNH = ME, MA, VT, and NH; NDSD = ND and SD; TB = tribal lands

Table J-11: Sulfate scaling factors for coal EGU tags in the Option A scenario

	2021	2023	2025	2030	2035	2040	2045
AL	0.563	0.604	0.61	0.695	0.601	0.616	0.621
AR	0.965	1.341	1.568	1.388	0.137	0.139	0.142
AZ	1.698	1.71	1.469	1.385	1.336	1.342	1.353
CA	0.631	0.471	0.631	0	0	0	0
CO	0.878	0.781	0.77	0.718	0.693	0.708	0.621
CTRI	0	0	0	0	0	0	0
DENJ	0	0	0	0	0	0	0
FL	0.432	0.548	0.556	0.459	0.625	0.542	0.528
GA	0.787	0.632	0.709	0.637	0.566	0.583	0.589
IA	0.642	0.499	0.471	0.458	0.432	0.435	0.392
IDORWA	NA	NA	NA	NA	NA	NA	NA
IL	0.504	0.527	0.521	0.523	0.504	0.487	0.456
IN	0.88	0.866	0.855	0.837	0.778	0.749	0.605
KS	0.885	0.967	1.006	0.887	0.74	0.829	0.74
KY	0.175	0.199	0.183	0.178	0.14	0.162	0.153
LA	0.227	0.433	0.427	0.443	0.443	0.419	0.418
MD	0.012	0.085	0.075	0.063	0	0.115	0.1
MEMANHVT	0.404	0.404	0.396	0.396	0.396	0.396	0.396
MI	0.649	0.581	0.851	0.891	0.665	0.664	0.619
MN	0.894	0.889	1.157	1.158	0.528	0.544	0.514
MO	1.168	1.255	1.227	1.234	1.322	1.214	1.209
MS	0.526	0.615	0.645	0.652	0.645	0.639	0.652
MT	0.525	0.525	0.515	0.599	0.599	0.599	0.599
NC	0.523	0.589	0.554	0.459	0.296	0.35	0.328
NDSD	0.58	0.597	0.581	0.575	0.571	0.579	0.553
NE	1.034	0.978	0.97	0.94	0.922	0.924	0.866
NM	1.213	1.214	1.205	1.096	1.016	0.926	0.923
NV	12.191	16.982	2.322	0.649	0.649	0.649	0.649
NY	0	0	0	0	0	0	0
OH	0.639	0.698	0.694	0.744	0.495	0.422	0.382
OK	0.831	1.177	1.226	0.913	0.791	0.872	0.796
PA	0.094	0.115	0.108	0.061	0.048	0.048	0.047
SC	1.481	1.608	1.638	1.446	1.054	1.104	1.106
TB	1.056	1.056	1.05	0.962	0.906	0.834	0.817
TN	0.286	0.349	0.357	0.391	0.327	0.386	0.372
TX	0.791	0.889	0.923	0.814	0.751	0.711	0.625
UT	1.347	1.347	1.357	1.318	1.407	1.387	1.206

Table J-11: Sulfate scaling factors for coal EGU tags in the Option A scenario

	2021	2023	2025	2030	2035	2040	2045
VA	0	0.05	0.021	0	0	0	0
WI	0.516	0.659	0.651	0.496	0.46	0.509	0.391
WV	1.363	0.857	0.844	0.813	0.519	0.51	0.471
WY	0.733	0.784	0.779	0.521	0.511	0.517	0.584

*CTRI = CT and RI; DENJ = DE and NJ; IDORWA = ID, OR, and WA; MEMAVTNH = ME, MA, VT, and NH; NDSD = ND and SD; TB = tribal lands

**NAs are shown where the modeled 2023 emissions were = 0 for any source apportionment tag

Table J-12: Sulfate scaling factors for non-coal EGU tags in the Option A scenario

	2021	2023	2025	2030	2035	2040	2045
AL	0.00	0.00	0.00	0.00	0.00	0.00	0.00
AR	0.00	0.00	0.00	0.00	0.00	0.00	0.00
AZ	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CA	0.17	0.17	0.21	0.00	0.00	0.01	0.01
CO	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CTRI	2.00	2.00	2.00	2.00	2.00	2.00	2.00
DENJ	2.50	2.50	2.50	2.50	2.50	2.50	2.50
FL	0.68	0.68	0.68	0.67	0.67	0.67	0.67
GA	0.04	0.09	0.09	0.10	0.28	0.32	0.31
IA	0.00	0.00	0.00	0.00	0.00	0.00	0.00
IDORWA	0.07	0.07	0.07	0.07	0.07	0.07	0.07
IL	0.00	0.00	0.00	0.00	0.00	0.00	0.00
IN	0.20	0.20	0.20	0.20	0.20	0.20	0.20
KS	0.00	0.00	0.00	0.00	0.00	0.00	0.00
KY	0.03	0.03	0.03	0.03	0.02	0.02	0.02
LA	0.06	0.06	0.06	0.06	0.06	0.06	0.06
MD	0.45	0.45	0.45	0.45	0.45	0.45	0.45
MEMANHVT	0.31	0.31	0.31	0.31	0.31	0.31	0.31
MI	0.26	0.07	0.07	0.06	0.06	0.06	0.06
MN	0.29	0.29	0.29	0.29	0.29	0.29	0.29
MO	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MS	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MT	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NC	0.01	0.01	0.01	0.01	0.00	0.00	0.00
NDSD	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NE	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NM	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NV	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NY	1.90	1.90	1.90	0.64	0.64	0.64	0.64
OH	0.08	0.08	0.08	0.08	0.08	0.08	0.08
OK	0.00	0.00	0.00	0.00	0.00	0.00	0.00
PA	0.04	0.04	0.04	0.04	0.04	0.04	0.04
SC	0.01	0.01	0.01	0.01	0.00	0.00	0.00
TB	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TN	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TX	0.04	0.04	0.04	0.04	0.04	0.04	0.04
UT	0.00	0.00	0.00	0.00	0.00	0.00	0.00
VA	0.20	0.21	0.20	0.20	0.20	0.20	0.20
WI	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table J-12: Sulfate scaling factors for non-coal EGU tags in the Option A scenario

	2021	2023	2025	2030	2035	2040	2045
WV	0.00	0.00	0.00	0.00	0.00	0.00	0.00
WY	0.00	0.00	0.00	0.00	0.00	0.00	0.00

*CTRI = CT and RI; DENJ = DE and NJ; IDORWA = ID, OR, and WA; MEMAVTNH = ME, MA, VT, and NH; NDSD = ND and SD; TB = tribal lands

Table J-13: Primary PM2.5 scaling factors for coal EGU tags in the Baseline scenario

	2021	2023	2025	2030	2035	2040	2045
AL	0.148	0.142	0.15	0.178	0.158	0.168	0.169
AR	0.715	1.184	1.32	0.686	0.286	0.289	0.301
AZ	1.11	1.139	1.04	0.766	0.734	0.735	0.735
CA	0.632	0.472	0.632	0	0	0	0
CO	1.939	1.694	1.694	1.612	1.537	1.575	1.41
CTRI	0	0	0	0	0	0	0
DENJ	0	0	0	0	0	0	0
FL	0.513	0.675	0.654	0.504	0.732	0.628	0.606
GA	0.361	0.302	0.311	0.35	0.297	0.321	0.325
IA	0.702	0.62	0.62	0.603	0.56	0.562	0.499
IDORWA	NA	NA	NA	NA	NA	NA	NA
IL	0.525	0.555	0.554	0.597	0.558	0.59	0.547
IN	1.905	1.797	1.804	1.827	1.769	1.716	1.535
KS	0.971	1.054	1.104	1.017	0.849	0.924	0.831
KY	1.156	1.314	1.221	1.369	1.127	1.413	1.345
LA	0.11	0.278	0.292	0.314	0.321	0.302	0.302
MD	0.02	0.134	0.115	0.099	0	0.278	0.206
MEMANHVT	0	0	0	0	0	0	0
MI	7.479	8.428	9.333	9.574	7.742	7.722	7.343
MN	1.279	1.478	1.523	1.141	0.85	0.896	0.7
MO	1.022	1.105	1.098	1.042	1.012	1.017	0.914
MS	0.212	0.253	0.276	0.279	0.279	0.276	0.279
MT	1.059	1.059	1.059	1.059	1.059	1.059	1.059
NC	0.38	0.433	0.336	0.25	0.169	0.174	0.17
NDSD	0.919	0.963	0.969	0.937	0.93	0.95	0.899
NE	0.587	0.526	0.532	0.488	0.462	0.465	0.431
NM	0.453	0.453	0.453	0.331	0.252	0.229	0.217
NV	0.783	1.108	0.651	0.181	0.181	0.181	0.181
NY	0	0	0	0	0	0	0
OH	0.424	0.443	0.442	0.421	0.291	0.268	0.253
OK	1.096	1.519	1.669	1.142	1.119	1.224	1.126
PA	0.296	0.342	0.318	0.202	0.155	0.155	0.155
SC	0.551	0.588	0.575	0.521	0.416	0.442	0.446
TB	0.574	0.574	0.577	0.577	0.577	0.577	0.577
TN	0.207	0.252	0.271	0.237	0.221	0.247	0.242
TX	1.095	1.231	1.355	1.187	1.12	1.154	1.095
UT	0.376	0.376	0.376	0.361	0.301	0.289	0.278
VA	0	0.161	0.075	0	0	0	0
WI	0.439	0.485	0.488	0.46	0.455	0.461	0.342
WV	0.707	0.611	0.584	0.562	0.333	0.327	0.312
WY	0.469	0.518	0.518	0.448	0.438	0.446	0.449

Table J-13: Primary PM2.5 scaling factors for coal EGU tags in the Baseline scenario

	2021	2023	2025	2030	2035	2040	2045

*CTRI = CT and RI; DENJ = DE and NJ; IDORWA = ID, OR, and WA; MEMAVTNH = ME, MA, VT, and NH; NDSD = ND and SD; TB = tribal lands

**NAs are shown where the modeled 2023 emissions were = 0 for any source apportionment tag

Table J-14: Primary PM2.5 scaling factors for non-coal EGU tags in the Baseline scenario

	2021	2023	2025	2030	2035	2040	2045
AL	1.226	1.162	1.193	1.191	1.325	1.345	1.45
AR	0.675	0.719	0.728	0.75	0.832	1.135	1.481
AZ	0.832	0.8	0.92	0.874	0.956	1.059	0.803
CA	1.719	1.595	1.492	0.661	0.64	0.666	0.414
CO	0.918	1.266	1.334	1.681	1.888	1.942	1.578
CTRI	1.794	1.726	1.715	1.484	1.404	1.42	1.451
DENJ	1.238	1.567	1.581	1.78	1.741	1.595	1.362
FL	1.236	1.238	1.247	1.236	1.27	1.318	1.354
GA	1.776	1.744	1.766	1.749	1.839	1.994	2.129
IA	2.096	2.258	2.223	2.548	3.028	2.827	2.034
IDORWA	1.495	1.495	1.512	1.471	1.495	1.551	1.635
IL	0.661	0.723	0.595	0.91	1.008	0.896	0.782
IN	1.274	1.325	1.295	1.359	1.783	2.179	2.419
KS	1.698	2.22	2.57	1.704	2.936	2.472	2.169
KY	1.143	1.208	1.84	2.299	3.035	3.37	4.146
LA	0.67	0.67	0.67	0.673	0.745	0.801	0.819
MD	2.525	2.55	2.55	2.59	2.7	2.8	2.843
MEMANHVT	0.928	0.903	0.892	0.786	0.715	0.702	0.729
MI	1.443	1.504	1.483	1.581	1.673	1.875	1.814
MN	0.742	0.773	0.757	0.771	1.02	1.019	0.722
MO	0.505	0.567	0.602	0.575	0.932	0.994	0.802
MS	1.054	1.033	1.043	1.05	1.218	1.201	1.245
MT	2.706	2.706	2.707	2.717	2.728	2.732	2.732
NC	1.963	1.935	2.006	2.164	2.033	2.07	2.164
NDSD	0.797	1.022	0.904	0.855	1.208	1.143	0.964
NE	0.75	0.802	0.763	0.697	0.79	0.721	0.696
NM	0.852	0.856	0.857	0.725	0.818	0.825	0.502
NV	2.3	2.268	2.166	2.19	2.325	2.405	2.846
NY	0.845	0.863	0.859	0.809	0.651	0.463	0.47
OH	1.224	1.31	1.265	1.485	1.659	1.75	1.937
OK	0.982	0.992	1.033	1.064	1.364	1.519	1.152
PA	1.529	1.639	1.662	1.698	1.807	1.725	1.852
SC	1.013	1.009	1.037	1.118	1.435	1.55	1.604
TB	0.033	0.116	0.31	0.307	0.32	1.125	0.38
TN	1.814	1.869	1.89	1.95	2.136	2.515	2.992
TX	1.065	1.027	1.018	1.004	1.079	1.137	0.634
UT	1.777	1.827	1.834	1.826	1.896	2.023	1.952
VA	1.636	1.788	1.711	2.128	2.215	2.074	1.91
WI	0.472	0.488	0.489	0.497	0.517	0.517	0.504
WV	0.032	0.032	0.034	0.065	5.385	7.522	9.484
WY	0.021	0.021	0.021	0.063	0.208	0.229	0.229

Table J-14: Primary PM2.5 scaling factors for non-coal EGU tags in the Baseline scenario

	2021	2023	2025	2030	2035	2040	2045

*CTRI = CT and RI; DENJ = DE and NJ; IDORWA = ID, OR, and WA; MEMAVTNH = ME, MA, VT, and NH; NDSD = ND and SD; TB = tribal lands

Table J-15: Primary $PM_{2.5}$ scaling factors for coal EGU tags in the Option A scenario

	2021	2023	2025	2030	2035	2040	2045
AL	0.147	0.142	0.15	0.178	0.158	0.168	0.169
AR	0.674	1.088	1.201	0.684	0.286	0.289	0.299
AZ	1.11	1.139	1.04	0.766	0.734	0.735	0.735
CA	0.632	0.472	0.632	0	0	0	0
CO	1.942	1.694	1.694	1.612	1.537	1.575	1.413
CTRI	0	0	0	0	0	0	0
DENJ	0	0	0	0	0	0	0
FL	0.531	0.675	0.647	0.545	0.72	0.628	0.602
GA	0.361	0.302	0.316	0.345	0.306	0.316	0.32
IA	0.705	0.639	0.623	0.607	0.562	0.563	0.501
IDORWA	NA	NA	NA	NA	NA	NA	NA
IL	0.416	0.435	0.435	0.446	0.442	0.438	0.43
IN	1.91	1.807	1.813	1.836	1.767	1.72	1.539
KS	0.971	1.059	1.11	1.019	0.85	0.937	0.834
KY	1.178	1.344	1.297	1.297	1.123	1.311	1.264
LA	0.137	0.29	0.293	0.314	0.321	0.302	0.302
MD	0.019	0.13	0.116	0.097	0	0.256	0.2
MEMANHVT	0.696	0.696	0.696	0.696	0.696	0.696	0.696
MI	7.47	8.629	9.374	9.584	7.744	7.723	7.354
MN	1.279	1.491	1.536	1.141	0.85	0.901	0.7
MO	1.023	1.113	1.097	1.042	1.015	1.019	0.915
MS	0.219	0.256	0.276	0.279	0.276	0.274	0.279
MT	1.059	1.059	1.059	1.059	1.059	1.059	1.059
NC	0.355	0.443	0.341	0.266	0.169	0.175	0.17
NDSD	0.92	0.964	0.968	0.937	0.93	0.95	0.898
NE	0.587	0.529	0.532	0.488	0.462	0.465	0.431
NM	0.453	0.453	0.453	0.331	0.252	0.223	0.217
NV	0.784	1.091	0.651	0.181	0.181	0.181	0.181
NY	0	0	0	0	0	0	0
OH	0.421	0.443	0.442	0.423	0.292	0.267	0.253
OK	1.095	1.51	1.671	1.214	1.119	1.224	1.126
PA	0.364	0.437	0.41	0.202	0.155	0.155	0.153
SC	0.551	0.57	0.595	0.509	0.417	0.445	0.447
TB	0.574	0.574	0.577	0.577	0.577	0.577	0.577
TN	0.209	0.261	0.266	0.505	0.451	0.533	0.499
TX	1.095	1.234	1.357	1.187	1.122	1.154	1.097
UT	0.376	0.376	0.376	0.361	0.301	0.288	0.278
VA	0	0.18	0.075	0	0	0	0
WI	0.439	0.485	0.488	0.459	0.445	0.46	0.342
WV	0.7	0.601	0.587	0.562	0.333	0.328	0.312
WY	0.468	0.518	0.522	0.448	0.438	0.446	0.449

Table J-15: Primary $PM_{2.5}$ scaling factors for coal EGU tags in the Option A scenario

	2021	2023	2025	2030	2035	2040	2045

*CTRI = CT and RI; DENJ = DE and NJ; IDORWA = ID, OR, and WA; MEMAVTNH = ME, MA, VT, and NH; NDSD = ND and SD; TB = tribal lands

**NAs are shown where the modeled 2023 emissions were = 0 for any source apportionment tag

Table J-16: Primary $PM_{2.5}$ scaling factors for non-coal EGU tags in the Option A scenario

	2021	2023	2025	2030	2035	2040	2045
AL	1.226	1.159	1.196	1.206	1.316	1.327	1.438
AR	0.68	0.722	0.733	0.75	0.833	1.116	1.482
AZ	0.84	0.804	0.924	0.88	0.956	1.06	0.817
CA	1.721	1.595	1.487	0.661	0.64	0.648	0.41
CO	0.872	1.265	1.362	1.692	1.89	1.956	1.602
CTRI	1.794	1.722	1.703	1.492	1.412	1.419	1.454
DENJ	1.234	1.56	1.575	1.772	1.725	1.591	1.355
FL	1.235	1.238	1.243	1.236	1.273	1.318	1.354
GA	1.781	1.744	1.772	1.775	1.867	2.024	2.149
IA	2.096	2.275	2.28	2.552	3.038	2.795	2.003
IDORWA	1.493	1.495	1.515	1.47	1.495	1.551	1.64
IL	0.667	0.73	0.606	0.903	0.994	0.89	0.774
IN	1.271	1.329	1.289	1.363	1.801	2.209	2.464
KS	1.698	2.248	2.621	1.709	2.903	2.551	2.149
KY	1.149	1.208	1.864	2.109	3.078	3.346	4.096
LA	0.67	0.67	0.672	0.673	0.744	0.8	0.821
MD	2.524	2.549	2.536	2.592	2.703	2.809	2.841
MEMANHVT	0.923	0.895	0.889	0.781	0.712	0.697	0.722
MI	1.442	1.499	1.487	1.585	1.673	1.875	1.816
MN	0.744	0.776	0.764	0.768	1.009	1.017	0.719
MO	0.509	0.57	0.6	0.575	0.91	0.985	0.823
MS	1.053	1.034	1.042	1.026	1.197	1.174	1.24
MT	2.706	2.707	2.707	2.717	2.728	2.73	2.732
NC	1.964	1.935	2.01	2.151	2.033	2.056	2.16
NDSD	0.799	1.003	0.92	0.853	1.208	1.143	0.982
NE	0.758	0.802	0.786	0.701	0.794	0.723	0.677
NM	0.852	0.856	0.858	0.72	0.818	0.825	0.501
NV	2.297	2.263	2.179	2.19	2.325	2.406	2.86
NY	0.842	0.858	0.853	0.801	0.645	0.463	0.469
OH	1.225	1.297	1.265	1.482	1.659	1.758	1.939
OK	0.997	0.999	1.034	1.053	1.365	1.494	1.178
PA	1.528	1.637	1.661	1.701	1.815	1.743	1.859
SC	1.012	1.012	1.028	1.103	1.431	1.541	1.599
TB	0.033	0.116	0.31	0.307	0.32	1.125	0.38
TN	1.815	1.914	1.932	1.841	1.991	2.237	2.804
TX	1.064	1.026	1.016	1.004	1.08	1.136	0.641
UT	1.756	1.824	1.834	1.827	1.896	2.026	1.945
VA	1.636	1.776	1.705	2.129	2.216	2.066	1.908
WI	0.472	0.488	0.488	0.497	0.517	0.519	0.501
WV	0.032	0.032	0.035	0.074	5.245	7.397	9.496
WY	0.021	0.021	0.021	0.063	0.208	0.229	0.229

Table J-16: Primary $PM_{2.5}$ scaling factors for non-coal EGU tags in the Option A scenario

	2021	2023	2025	2030	2035	2040	2045

*CTRI = CT and RI; DENJ = DE and NJ; IDORWA = ID, OR, and WA; MEMAVTNH = ME, MA, VT, and NH; NDSD = ND and SD; TB = tribal lands

J.3 Air Quality Surface Results

Figure J-12 through Figure J-32 present the model-predicted changes in May-Sep MDA8 ozone, Apr-Oct MDA1 ozone and annual mean $PM_{2.5}$ concentrations between the baseline and Option A for 2021, 2023, 2025, 2030, 2035, 2040 and 2045 calculated as Option A minus the baseline. The spatial patterns shown in the figures are a result of (1) of the spatial distribution of EGU sources that are predicted to have changes in emissions and (2) of the physical or chemical processing that the model simulates in the atmosphere. The spatial fields used to create these maps serve as an input to the benefits analysis.

Figure J-12: Map of Change in May-Sep MDA8 Ozone (ppb): 2021 Option A – Baseline

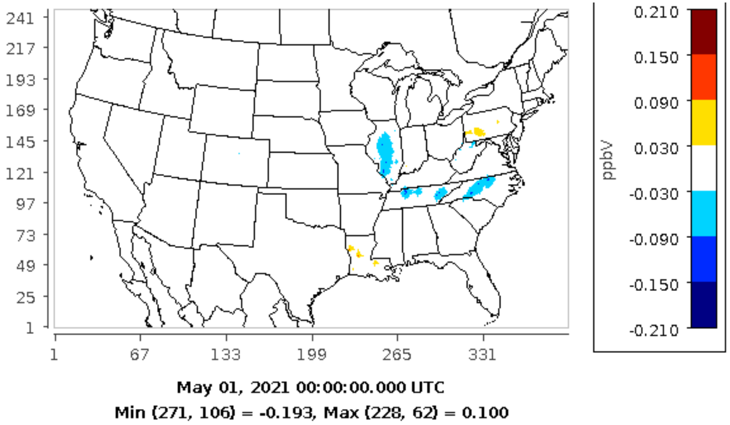


Figure J-13: Map of Change in Apr-Oct MDA1 Ozone (ppb): 2021 Option A – Baseline

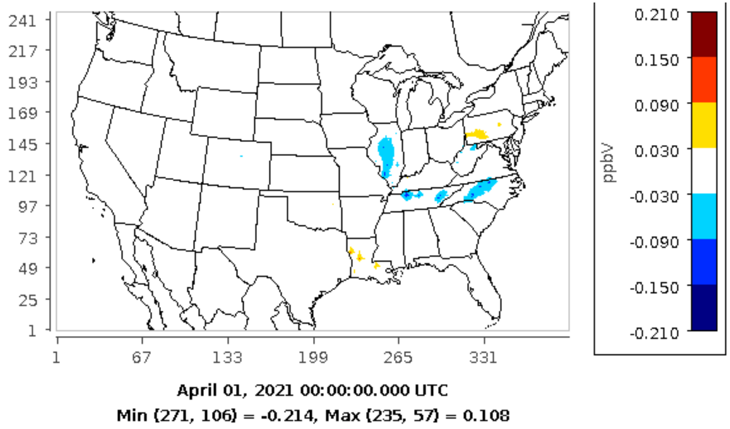
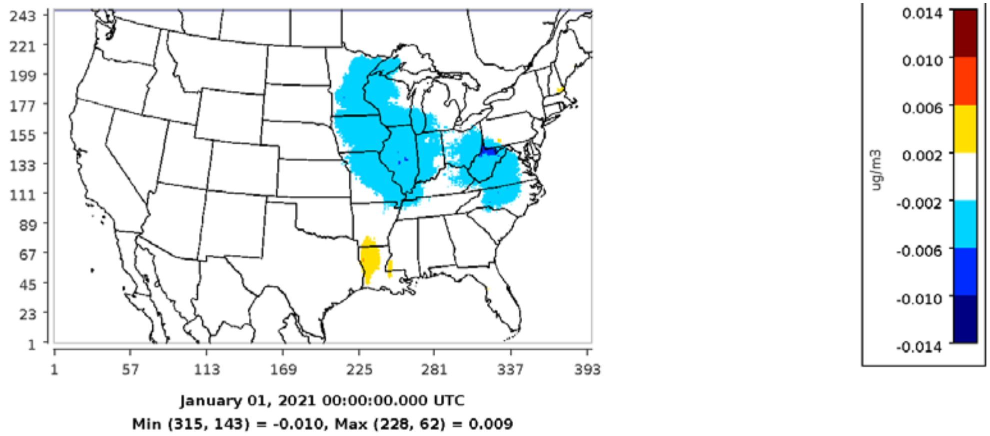


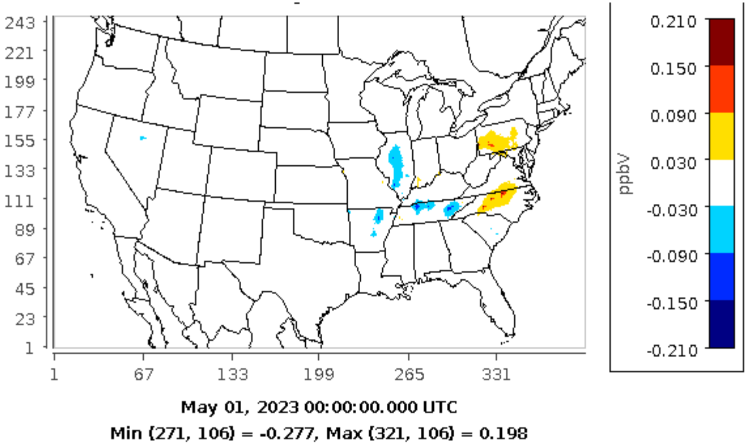
Figure J-14: Map of Change in Annual Mean $PM_{2.5}$ ($\mu g/m^3$): 2021 Option A – Baseline



January 01, 2021 00:00:00.000 UTC

Min (315, 143) = -0.010, Max (228, 62) = 0.009

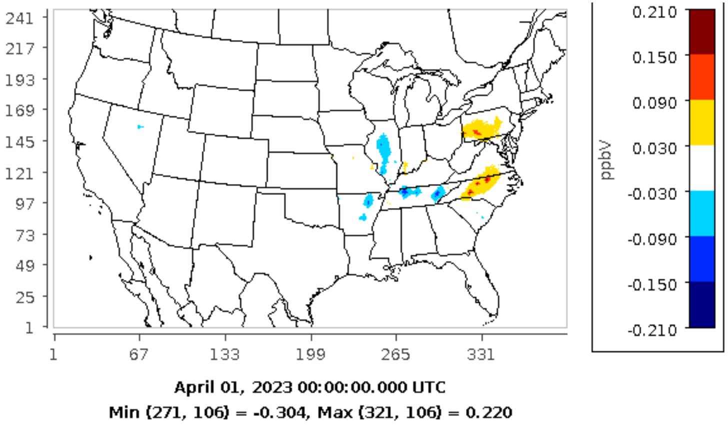
Figure J-15: Map of Change in May-Sep MDA8 Ozone (ppb): 2023 Option A – Baseline



May 01, 2023 00:00:00.000 UTC

Min (271, 106) = -0.277, Max (321, 106) = 0.198

Figure J-16: Map of Change in Apr-Oct MDA1 Ozone (ppb): 2023 Option A – Baseline



April 01, 2023 00:00:00.000 UTC

Min (271, 106) = -0.304, Max (321, 106) = 0.220

Figure J-17: Map of Change in Annual Mean $PM_{2.5}$ ($\mu g/m^3$): 2023 Option A – Baseline

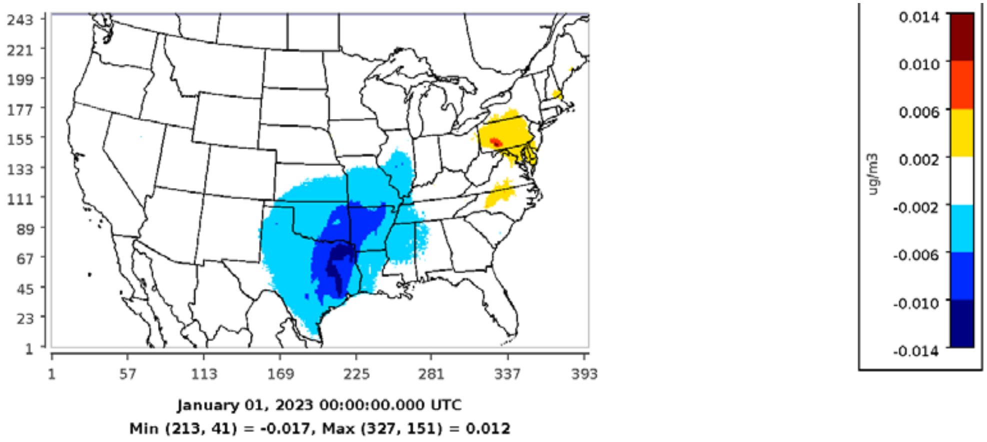


Figure J-18: Map of Change in May-Sep MDA8 Ozone (ppb): 2025 Option A – Baseline

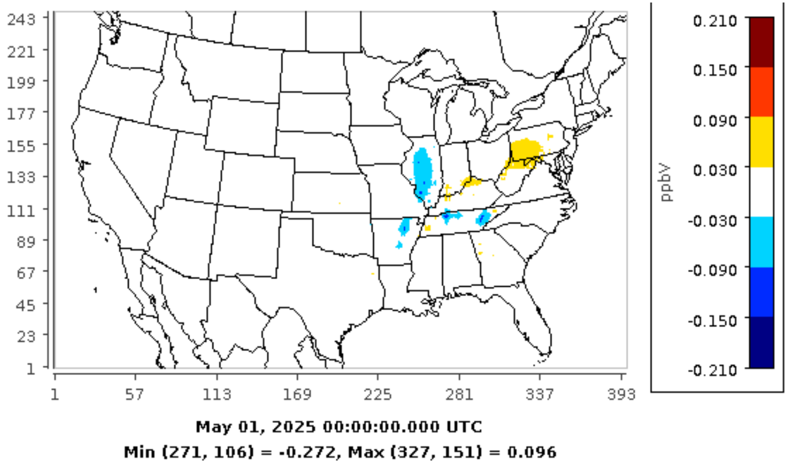


Figure J-19: Map of Change in Apr-Oct MDA1 Ozone (ppb): 2025 Option A – Baseline

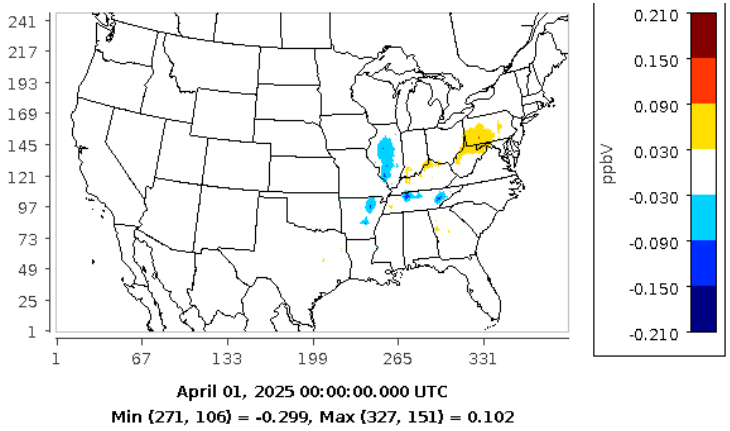


Figure J-20: Map of Change in Annual Mean $PM_{2.5}$ ($\mu g/m^3$): 2025 Option A – Baseline

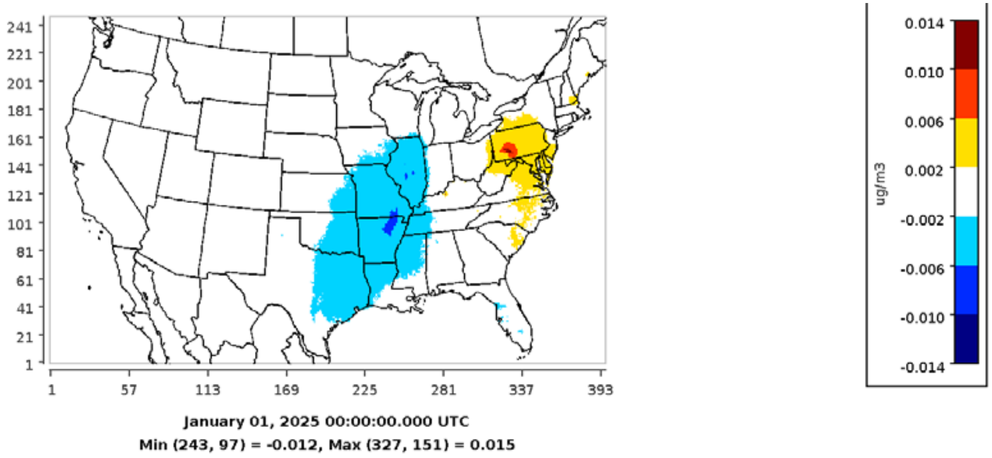


Figure J-21: Map of Change in May-Sep MDA8 Ozone (ppb): 2030 Option A – Baseline

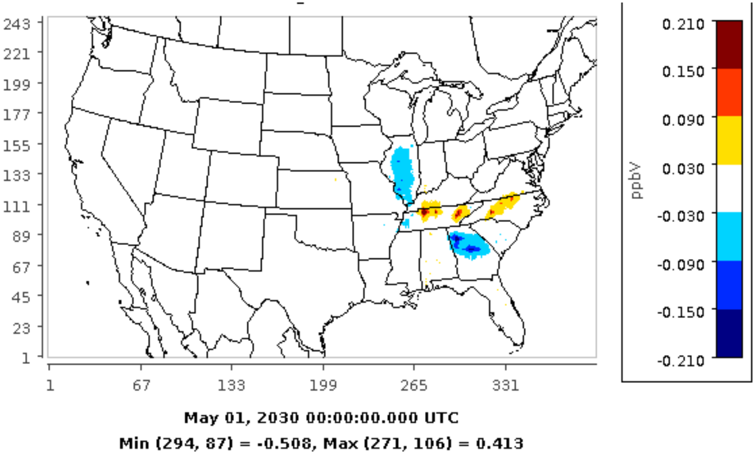


Figure J-22: Map of Change in Apr-Oct MDA1 Ozone (ppb): 2030 Option A – Baseline

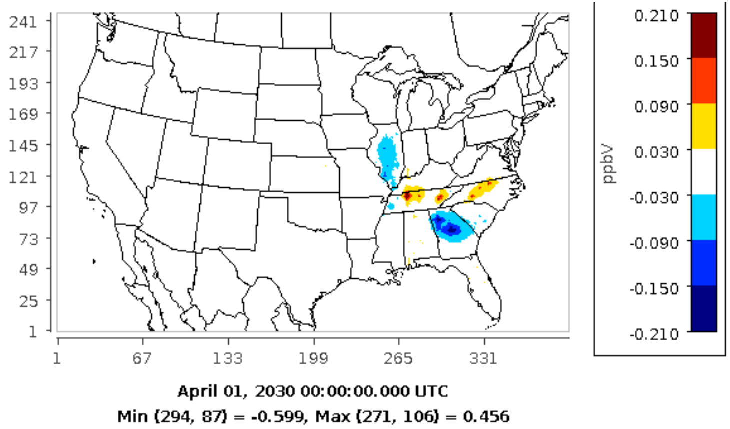


Figure J-23: Map of Change in Annual Mean $PM_{2.5}$ ($\mu g/m^3$): 2030 Option A – Baseline

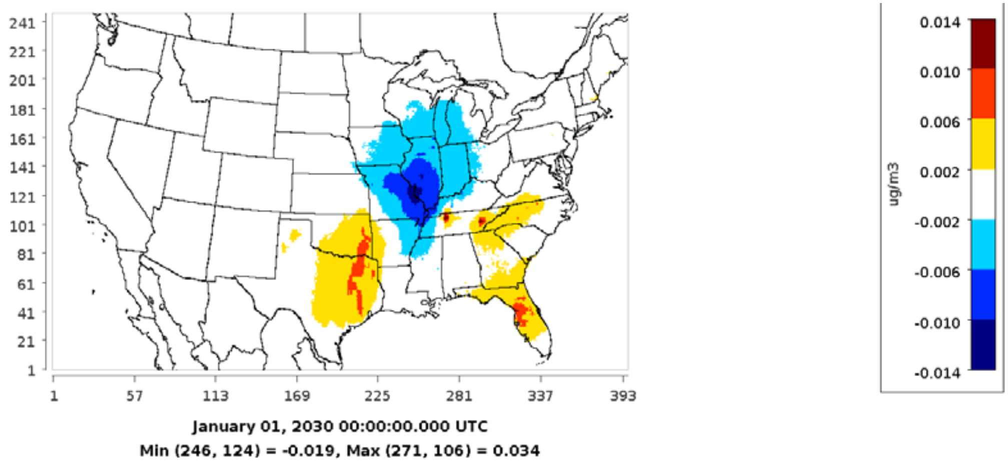


Figure J-24: Map of Change in May-Sep MDA8 Ozone (ppb): 2035 Option A – Baseline

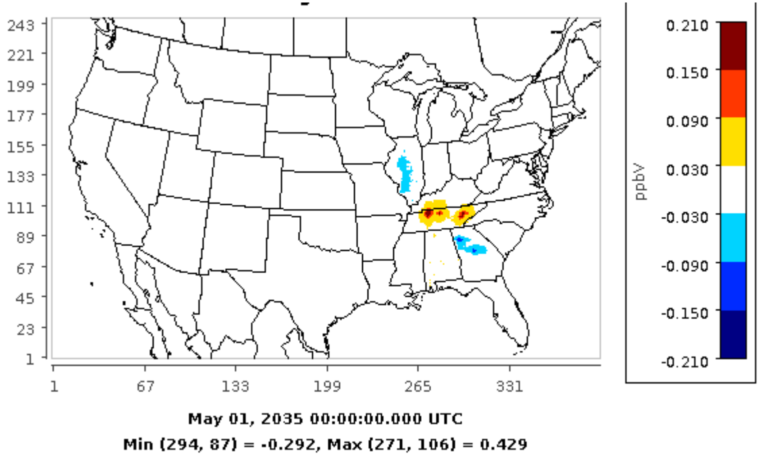


Figure J-25: Map of Change in Apr-Oct MDA1 Ozone (ppb): 2035 Option A – Baseline

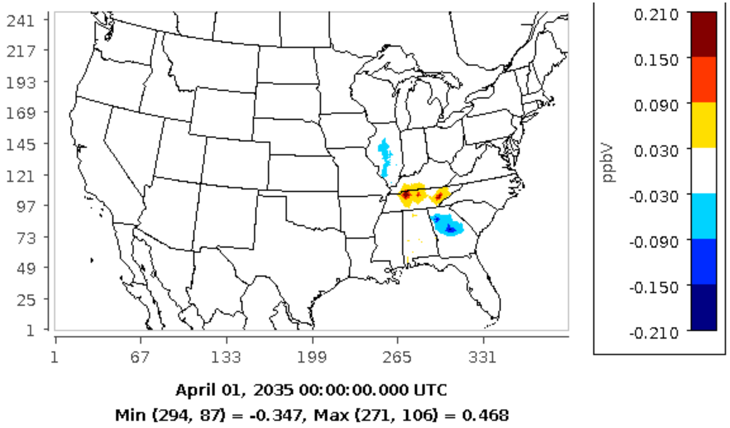


Figure J-26: Map of Change in Annual Mean $PM_{2.5}$ ($\mu g/m^3$): 2035 Option A – Baseline

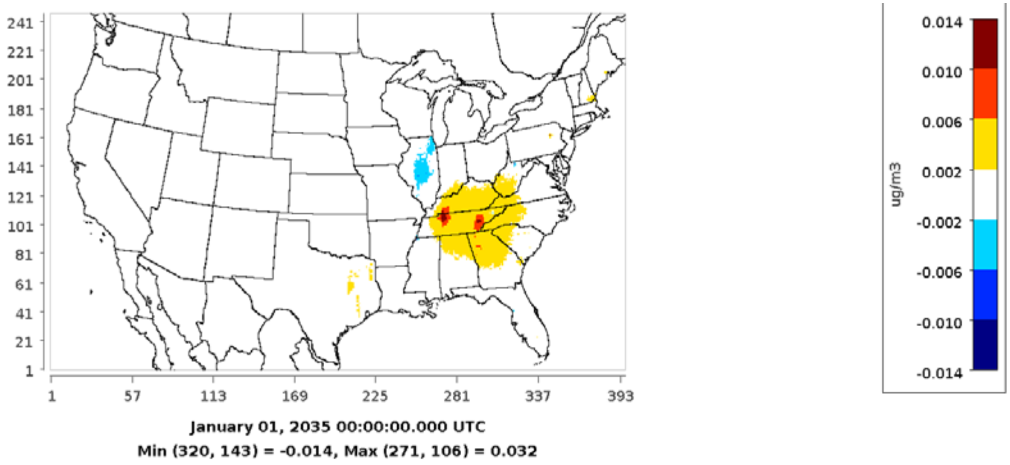


Figure J-27: Map of Change in May-Sep MDA8 Ozone (ppb): 2040 Option A – Baseline

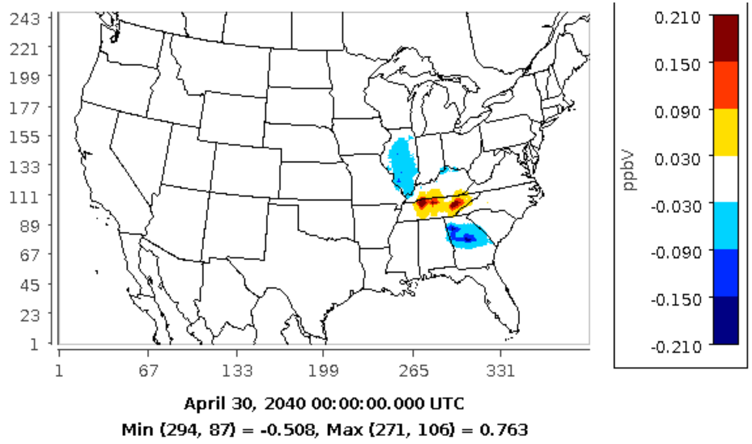


Figure J-28: Map of Change in Apr-Oct MDA1 Ozone (ppb): 2040 Option A – Baseline

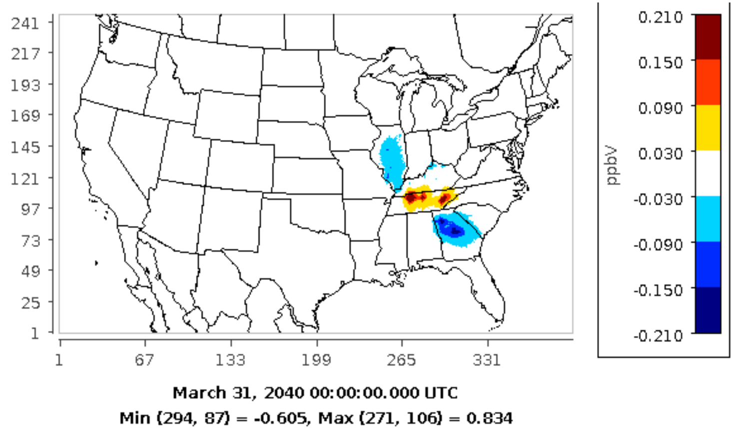


Figure J-29: Map of Change in Annual Mean $PM_{2.5}$ ($\mu g/m^3$): 2040 Option A – Baseline

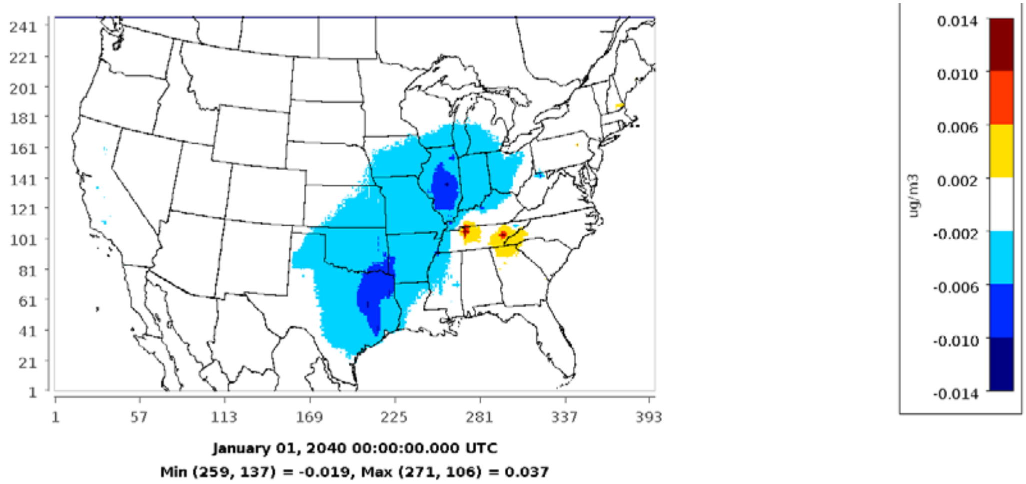


Figure J-30: Map of Change in May-Sep MDA8 Ozone (ppb): 2045 Option A – Baseline

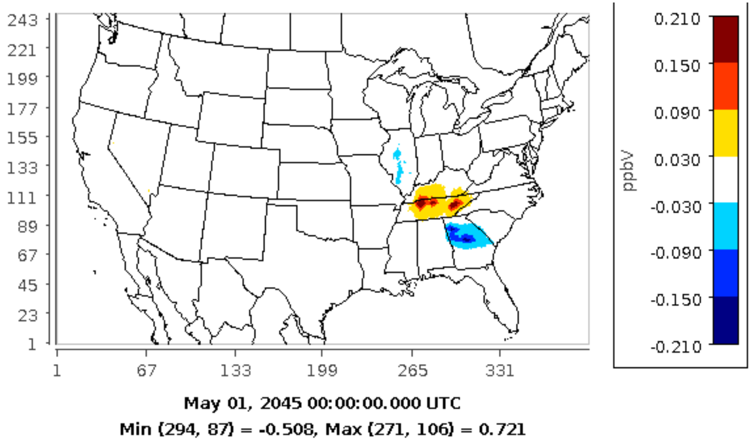


Figure J-31: Map of Change in Apr-Oct MDA1 Ozone (ppb): 2045 Option A – Baseline

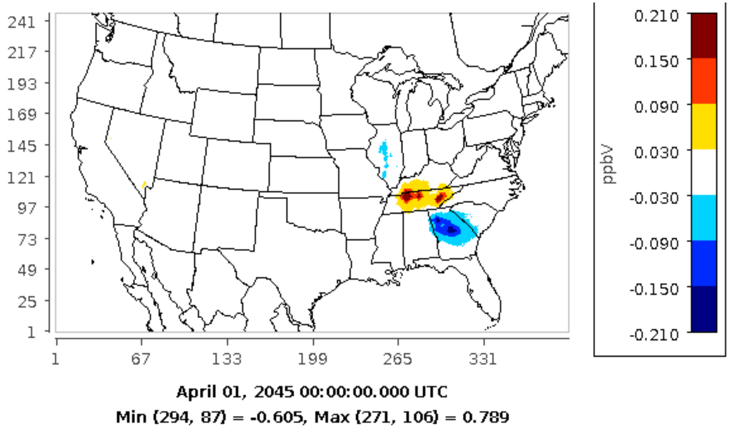
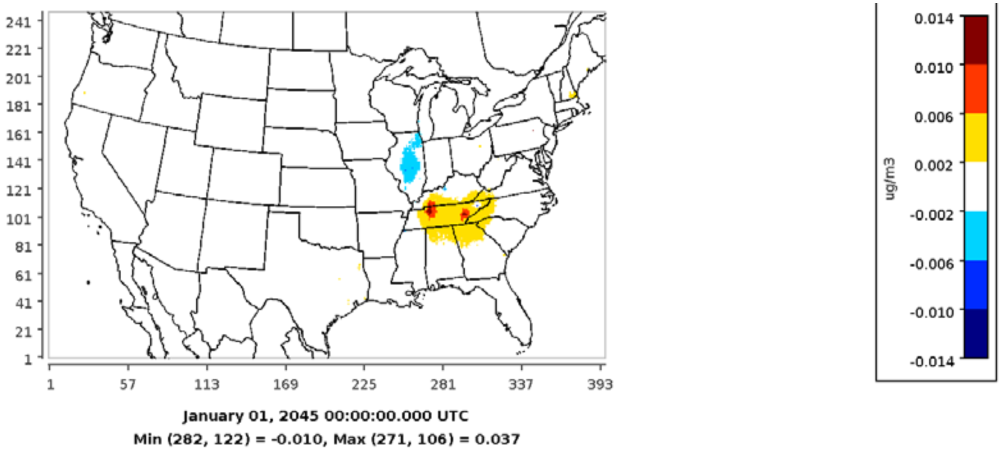


Figure J-32: Map of Change in Annual Mean $PM_{2.5}$ ($\mu g/m^3$): 2045 Option A – Baseline



J.4 Uncertainties and Limitations of Air Quality Methodology

One limitation of the scaling methodology for creating $PM_{2.5}$ surfaces associated with the baseline or Option A scenarios described above is that it treats air quality changes from the tagged sources as linear and additive. It therefore does not account for nonlinear atmospheric chemistry and does not account for interactions between emissions of different pollutants and between emissions from different tagged sources. This is consistent with how air quality estimations have been treated in past regulatory analyses (U.S. EPA, 2012, 2019i, 2020c). Air quality is calculated in the same manner for the baseline and the Option A scenario, so any uncertainty associated with these assumptions is carried through both sets of scenarios in the same manner and is thus not expected to impact the air quality differences between scenarios. In addition, emissions changes between scenarios are relatively small compared to modeled 2023 totals. Previous studies have shown that air pollutant concentrations generally respond linearly to small emissions changes of up to 30 percent (D. Cohan & Napelenok, 2011; D. S. Cohan *et al.*, 2005; Dunker *et al.*, 2002; Koo *et al.*, 2007; Napelenok *et al.*, 2006; Zavala *et al.*, 2009) and that linear scaling from source apportionment can do a reasonable job of representing impacts of 100 percent of emissions from individual sources (Baker & Kelly, 2014). Therefore, it is reasonable to expect that the differences between the baseline and Option A scenarios can be adequately represented using this methodology.

A second limitation is that the source apportionment $PM_{2.5}$ contributions represent the spatial and temporal distribution of the emissions from each source tag as they occur in the 2023 modeled case. Thus, the contribution modeling results do not allow EPA to represent any changes to "within tag" spatial distributions. As a result, the method does not account for any changes of spatial patterns that would result from changes in the relative magnitude of sources within a source tag in the scenarios investigated here.

Finally, the 2023 modeled concentrations themselves have some uncertainty. While all models have some level of inherent uncertainty in their formulation and inputs, the base-year 2011 model outputs have been evaluated elsewhere against ambient measurements (U.S. EPA, 2017b, 2019i) and have been shown to adequately reproduce spatially and temporally varying ozone and $PM_{2.5}$ concentrations.