United States Environmental Protection Agency | Office of Water Washington, DC 20460 | EPA-821-R-23-003 February 28, 2023

# Benefit and Cost Analysis for Proposed Supplemental Effluent Limitations Guidelines and Standards for the Steam Electric Power Generating Point Source Category

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EPA-821-R-23-003

February 28, 2023

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

| | |
|---|---|
| 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 |
| 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 |
| OWTP | Willingness-to-pay for a one-point WQI improvement (one-point WTP) |
| 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 proposing 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 promulgated in October 2020 (85 FR 64650). The proposed rule revises certain best available technology economically achievable (BAT) effluent limitations and pretreatment standards for existing sources (PSES) for three wastestreams: flue gas desulfurization (FGD) wastewater, bottom ash (BA) transport water, and combustion residual leachate (CRL).

## Regulatory Options

EPA analyzed four regulatory options, summarized in Table ES-1. The options are labeled Option 1 through Option 4 according to increasing stringency. All options include the same technology basis for CRL (chemical precipitation) while incrementally increasing controls on FGD wastewater, BA transport water, or both. EPA identifies one preferred option in the proposed rule, Option 3.

The baseline for the benefit and social cost analyses reflects existing ELG requirements in absence of this proposed EPA action. i.e., the 2020 ELG. As detailed in this report, EPA calculated the difference between the baseline and regulatory Options 1 through 4 to determine the net incremental effect of the regulatory options. In general, the proposed regulatory options are estimated to result in smaller pollutant loads, improved environmental conditions, and net benefits.

## 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 0 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.

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-1: Regulatory Options Analyzed for the Proposed Rule**

| Wastestream | Subcategory | Technology Basis for BAT/PSES Regulatory Options[a] | | | | |
|---|---|---|---|---|---|---|
| | | **2020 Rule (Baseline)** | **Option 1** | **Option 2** | **Option 3** | **Option 4** |
| FGD Wastewater | NA (default unless in subcategory)[b] | CP + Bio | CP + Bio | CP + Membrane | CP + Membrane | CP + Membrane |
| | Boilers permanently ceasing the combustion of coal by 2028 | SI | SI | SI | SI | SI |
| | Early adopters or boilers permanently ceasing the combustion of coal by 2032 | NS | NS | CP + Bio | CP + Bio | NS |
| | High FGD Flow Facilities or Low Utilization Boilers | CP | CP + Bio | CP + Membrane | CP + Membrane | CP + Membrane |
| BA Transport Water | NA (default unless in subcategory)[b] | HRR | HRR | HRR | ZLD | ZLD |
| | Boilers permanently ceasing the combustion of coal by 2028 | SI | SI | SI | SI | SI |
| | Early adopters or boilers permanently ceasing the combustion of coal by 2032 | NS | NS | NS | HRR | NS |
| | Low Utilization Boilers | BMP Plan | HRR | HRR | ZLD | ZLD |
| CRL | NA (default)[b] | BPJ | CP | CP | CP | CP |

Abbreviations: BMP = Best Management Practice; CP = Chemical Precipitation; HRR = High Recycle Rate Systems; SI = Surface Impoundment; ZLD = Zero Liquid Discharge; NS = Not subcategorized (default technology basis applies); NA = Not applicable

a. See TDD for a description of these technologies (U.S. EPA, 2023d).

b. The table does not present existing subcategories included in the 2015 and 2020 rules 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, 2022*

**Table ES-2: Summary of Total Annualized Benefits for Regulatory Options, Compared to Baseline, at 3 Percent (Millions of 2021$)**

| Benefit Category | Option 1 | Option 2 | Option 3 | Option 4 |
|---|---|---|---|---|
| **Human Health** | **$3.39** | **$12.36** | **$12.72** | **$15.81** |
| Changes in IQ losses in children from exposure to lead[a] | <$0.01 | <$0.01 | $0.01 | $0.01 |
| Changes in IQ losses in children from exposure to mercury | $2.94 | $2.99 | $3.11 | $3.11 |
| Changes in cancer risk from disinfection by-products in drinking water | $0.45 | $9.37 | $9.61 | $12.70 |
| **Ecological Conditions and Recreational Uses Changes** | **$3.02** | **$3.82** | **$4.09** | **$4.27** |
| Use and nonuse values for water quality changes[b] | $3.02 | $3.82 | $4.09 | $4.27 |
| **Market and Productivity Effects[a]** | **<$0.01** | **<$0.01** | **<$0.01** | **<$0.01** |
| Changes in dredging costs[a] | <$0.01 | <$0.01 | <$0.01 | <$0.01 |
| **Air Quality-Related Effects** | **$690** | **$1,320** | **$1,540** | **$1,650** |
| Climate change effects from changes in $CO_2$ emissions[c] | $190 | $370 | $440 | $450 |
| Human health effects from changes in $NO_X$, $SO_2$, and $PM_{2.5}$ emissions[d] | $500 | $950 | $1,100 | $1,200 |
| **Total[e]** | **$696** | **$1,336** | **$1,557** | **$1,670** |

a. "<$0.01" indicates that monetary values are greater than $0 but less than $0.01 million.

b. Value reflects the main willingness-to-pay estimates. See Chapter 6 for details.

c. Values for air-quality related effects are rounded to two significant figures. EPA estimated the air quality-related benefits for Option 3. EPA extrapolated estimates of air quality-related benefits for Options 1, 2, and 4 from the estimate for Option 3 that is based on IPM outputs. See Chapter 8 for details.

d. 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.

e. Values for individual benefit categories may not sum to the total due to independent rounding. Range is based on the air quality-related effects.

*Source: U.S. EPA Analysis, 2022*

**Table ES-3: Summary of Total Annualized Benefits for Regulatory Options, Compared to Baseline, at 7 Percent (Millions of 2021$)**

| Benefit Category | Option 1 | Option 2 | Option 3 | Option 4 |
|---|---|---|---|---|
| **Human Health** | **$0.82** | **$6.64** | **$6.82** | **$8.84** |
| Changes in IQ losses in children from exposure to lead[a] | <$0.01 | <$0.01 | <$0.01 | <$0.01 |
| Changes in IQ losses in children from exposure to mercury | $0.54 | $0.55 | $0.58 | $0.58 |
| Changes in cancer risk from disinfection by-products in drinking water | $0.28 | $6.09 | $6.24 | $8.26 |
| **Ecological Conditions and Recreational Uses Changes** | **$2.64** | **$3.32** | **$3.56** | **$3.73** |
| Use and nonuse values for water quality changes[b] | $2.64 | $3.32 | $3.56 | $3.73 |
| **Market and Productivity Effects[d]** | **<$0.01** | **<$0.01** | **<$0.01** | **<$0.01** |
| Changes in dredging costs[d] | <$0.01 | <$0.01 | <$0.01 | <$0.01 |
| **Air Quality-Related Effects** | $570 | $1,070 | $1,280 | $1,320 |
| Climate change effects from changes in $CO_2$ emissions[c] | $190 | $370 | $440 | $450 |
| Human health effects from changes in $NO_X$, $SO_2$, and $PM_{2.5}$ emissions[d] | $380 | $700 | $840 | $870 |
| **Total[e]** | **$573** | **$1,080** | **$1,290** | **$1,333** |

a. "<$0.01" indicates that monetary values are greater than $0 but less than $0.01 million.

b. Value reflects the main willingness-to-pay estimates. See Chapter 6 for details.

c. Values for air-quality related effects are rounded to two significant figures. EPA estimated the air quality-related benefits for Option 3. EPA extrapolated estimates of air quality-related benefits for Options 1, 2, and 4 from the estimate for Option 3 that is based on IPM outputs. See Chapter 8 for details.

d. 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.

e. Values for individual benefit categories may not sum to the total due to independent rounding. Range is based on the air quality-related effects.

*Source: U.S. EPA Analysis, 2022*

### Social Costs of Regulatory Options

Table ES-4 (below) 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 additional costs across regulatory options and discount rates. 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, 2023c).

### 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-4 presents the monetized benefits and 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 2021$)**

| Regulatory Option | Total Monetized Benefits[a] | Total Social Costs |
|---|---|---|
| **3% Discount Rate** | | |
| Option 1 | $696 | $88.4 |
| Option 2 | $1,336 | $167.0 |
| Option 3 | $1,557 | $200.3 |
| Option 4 | $1,670 | $207.2 |
| **7% Discount Rate** | | |
| Option 1 | $573 | $96.6 |
| Option 2 | $1,080 | $180.4 |
| Option 3 | $1,290 | $216.5 |
| Option 4 | $1,333 | $224.1 |

a. EPA estimated the air quality-related benefits for Option 3. EPA extrapolated estimates of air quality-related benefits for Options 1, 2, and 4 from the estimate for Option 3 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.

*Source: U.S. EPA Analysis, 2022.*

# 1 Introduction

EPA is proposing to revise the technology-based ELGs for the steam electric power generating point source category, 40 CFR part 423, which EPA promulgated in October 2020 (85 FR 64650). The proposed rule would revise certain effluent limitations based on BAT and pretreatment standards for existing sources for three wastestreams: flue gas desulphurization (FGD) wastewater, bottom ash (BA) transport water, and combustion residual leachate (CRL).[1]

This document presents an analysis of the benefits and social costs of the regulatory options and complements other analyses EPA conducted in support of this proposal, described in separate documents:

- *Environmental Assessment for Proposed Supplemental Effluent Guidelines and Standards for the Steam Electric Power Generating Point Source Category* (EA; U.S. EPA, 2023a). The *EA* summarizes the potential environmental and human health impacts that are estimated to result from the proposed regulatory options, if implemented.
- *Technical Development Document for Proposed Supplemental Effluent Guidelines and Standards for the Steam Electric Power Generating Point Source Category* (TDD; U.S. EPA, 2023d). The TDD summarizes the technical and engineering analyses supporting the proposed rule. The TDD presents EPA's updated analyses supporting the revisions to limitations and standards applicable to discharges of FGD wastewater, BA transport water, and leachate. These updates include additional data collection that has occurred since publication of the 2020 rule, updates to the industry (*e.g.*, retirements, treatment updates), cost methodologies, pollutant removal estimates, and explanations for the calculation of the effluent limitations and standards.
- *Regulatory Impact Analysis for Proposed Supplemental Revisions to the Effluent Limitations Guidelines and Standards for the Steam Electric Power Generating Point Source Category* (RIA; U.S. EPA, 2023c). 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 11 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.
- *Environmental Justice Analysis for Proposed Supplemental Revisions to the Effluent Limitations Guidelines and Standards for the Steam Electric Power Generating Point Source Category (*EJA; U.S. Environmental Protection Agency, 2023b). This report presents a profile of the communities and populations potentially impacted by this proposal, analysis of the distribution of impacts in the baseline and proposed changes, and summary of input from potentially impacted communities that EPA met with prior to the proposal.

[1] The proposed rule also solicits comment on BAT for legacy wastewater but does not include BAT or PSES for that wastewater. Thus, for purposes of estimating benefits and costs, this report does not discuss legacy wastewater further.

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 proposed 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 870 steam electric power plants in the universe identified by EPA, only those coal-fired power plants that discharge FGD wastewater, BA transport water or CRL may incur compliance costs under the proposed regulatory options. After accounting for planned retirements and fuel conversions, EPA estimated that 163 coal-fired power plants will be operating after December 31, 2028, and of those, an estimated 93 steam electric power plants generate the relevant wastestreams and may incur costs to meet the effluent limits under one or more regulatory options. See TDD and RIA for details (U.S. EPA, 2023c, 2023d).

## 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, technology adoption status, and scrubber purge flow (see TDD for a detailed discussion of the options and the associated treatment technology bases).

The baseline for this analysis reflects applicable requirements (in absence of the proposed rule). The baseline includes the 2020 rule (85 FR 64650). 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.

The Agency estimated and presents in this report the water quality and other environmental effects of FGD wastewater, BA transport water, and leachate discharges under both the 2020 rule baseline and regulatory options 1 through 4 presented in Table 1-1. The Agency calculated the difference between the baseline and the regulatory options to determine the net effect of each regulatory option. EPA is proposing Option 3 as the preferred regulatory option.

**Table 1-1: Regulatory Options Analyzed for the Proposed Rule**

| Wastestream | Subcategory | Technology Basis for BAT/PSES Regulatory Options[a] | | | | |
|---|---|---|---|---|---|---|
| | | Baseline | Option 1 | Option 2 | Option 3 | Option 4 |
| FGD Wastewater | NA (default unless in subcategory)[b] | CP + Bio | CP + Bio | CP + Membrane | CP + Membrane | CP + Membrane |
| | Boilers permanently ceasing the combustion of coal by 2028 | SI | SI | SI | SI | SI |
| | Early adopters or boilers permanently ceasing the combustion of coal by 2032 | NS | NS | CP + Bio | CP + Bio | NS |
| | High FGD Flow Facilities or Low Utilization Boilers | CP | CP + Bio | CP + Membrane | CP + Membrane | CP + Membrane |
| BA Transport Water | Boilers permanently ceasing the combustion of coal by 2028 | SI | SI | SI | SI | SI |
| | Early adopters or boilers permanently ceasing the combustion of coal by 2032 | NS | NS | NS | HRR | NS |
| | Low Utilization Boilers | BMP Plan | HRR | HRR | ZLD | ZLD |
| | NA (default)[b] | BPJ | CP | CP | CP | CP |
| CRL | NA (default unless in subcategory)[b] | CP + Bio | CP + Bio | CP + Membrane | CP + Membrane | CP + Membrane |

Abbreviations: BMP = Best Management Practice; CP = Chemical Precipitation; HRR = High Recycle Rate Systems; SI = Surface Impoundment; ZLD = Zero Liquid Discharge; NS = Not subcategorized (default technology basis applies); NA = Not applicable

a. See TDD for a description of these technologies (U.S. EPA, 2023d).

b. The table does not present existing subcategories included in the 2015 and 2020 rules 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, 2022*

## 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[2] of the regulatory options:

1. All values are presented in 2021 dollars;
2. Future benefits and costs are discounted using rates of 3 percent and 7 percent back to 2024, which is the expected year for the final rule publication;
3. Benefits and costs are analyzed over a 25-year period (2025 to 2049) which covers the years when plants implement wastewater treatment technologies to meet the revised ELGs (2025-2029) and the subsequent life of these technologies (20 years);
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 net benefits (e.g., improvements in environmental conditions or social welfare) compared to 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 and 2020 rules (U.S. EPA, 2015a, 2020b). In analyzing the regulatory options, however, EPA made several changes relative to the analysis of the 2020 rule:

- EPA used revised inputs that reflect the costs and loads estimated for each of the four regulatory options (see TDD and RIA for details; U.S. EPA, 2023c, 2023d). Like the analysis of the 2020 rule, EPA estimated loading reductions for two periods (2025-2029 and 2030-2049) during the overall period of analysis (2025-2049) to account for transitional conditions when different plants are in the process of installing technologies to meet the proposed requirements.
- 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 2020 final rule. EPA also incorporated updated information on the technologies and other controls that plants employ. See the TDD for details on the changes (U.S. EPA, 2023d).
- 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*.

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

### *1.3.1 Constant Prices*

This BCA applies a year 2021 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).[3]

### *1.3.2 Discount Rate and Year*

This BCA generally 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. One exception to this practice is discounting of the benefits of avoided greenhouse gas emissions for which EPA uses values of the social cost of carbon dioxide (SC-$CO_2$) developed by the Interagency Working Group on the Social Cost of Greenhouse Gases (IWG) using discount rates of 2.5 percent, 3 percent, and 5 percent. Because greenhouse gases are long-lived and subsequent damages of current emissions can occur over a long time, the approach to discounting greatly influences the present value of future damages. The IWG published a set of four SC-$CO_2$ values for use in benefit-cost analyses (IWG, 2021): an average value resulting from integrated assessment model runs for each of three discount rates (2.5 percent, 3 percent, and 5 percent), plus a fourth value, selected as the 95$^{th}$ percentile of estimates based on a 3 percent discount rate.[4] Section 8.2 provides additional details on climate change-related benefits estimated using these different discount rates. When summarizing total annualized benefits, EPA includes climate-related benefits estimated using the 3-percent average SC-$CO_2$ values even when other costs and benefits are discounted at 7 percent.

All future cost and benefit values are discounted back to 2024.[5]

### *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 described in greater detail in the NPRM, EPA is establishing availability timing for BAT limitations that is "as soon as possible" after the effective date of any final rule but "no later than" five years from the effective date (*i.e.*, a 2029 deadline). 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 control technologies to meet the applicable rule limitations and

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3 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. EPA, 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.

4 The IWG included the fourth value to provide information on potentially higher-than-expected economic impacts from climate change, conditional on the 3 percent estimate of the discount rate (IWG, 2021).

5 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 2020 rule and used 2018 dollars and discounted benefits and costs to 2020 (see U.S. Environmental Protection Agency, 2020b).

standards as their permits are renewed, and no later than December 31, 2029. This schedule 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 2049 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 2029.

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 (2025-2029 and 2030-2049) within the overall analysis period (2025-2049). 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 the analysis of 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 (25 years).

### *1.3.6 Population and Income Growth*

To account for future population growth or decline, EPA used Woods & Poole population forecasts for the United States (U.S. Census Bureau, 2017; Woods & Poole Economics Inc., 2021). EPA used the growth projections for each year to adjust affected population estimates for future years (*i.e.*, from 2025 to 2049).

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 income adjustment factors, EPA calculated income growth factors using historical and projected “real disposable personal income” estimates (U.S. Energy Information Administration, 2021). For the VSL calculations, EPA used the VSL value in 1990 dollars ($4.8 million) and multiplied the value by the income growth rate (relative to 1990) for the applicable analysis year and an income elasticity of 0.4 (U.S. EPA, 2010a). For the WTP for water quality improvements, EPA multiplied income estimates by the income growth rate, relative to 2019, for the applicable analysis period year (*i.e.*, from 2025 to 2049).[6]

## 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 four regulatory options analyzed for this proposal.
- Chapter 3 describes EPA's estimates of the environmental changes resulting from the regulatory options, including water quality modeling that underlays the Agency's 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 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 describes benefits from changes in maintenance dredging of navigational channels and reservoirs.
- Chapter 10 summarizes monetized benefits across benefit categories.
- Chapter 11 summarizes the social costs of the regulatory options.
- Chapter 12 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 13 provides references cited in the text.

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

6 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.

# 2 Benefits Overview

This chapter provides an overview of the estimated welfare effects to society resulting from changes in pollutant loadings due to implementation of the main regulatory options analyzed for the proposed 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 TDD provides further detail on the loading changes (U.S. EPA, 2023d). As described in Section 3.2, EPA anticipates a transition period and estimated loadings during interim years before all plants have implemented control technologies to meet the applicable rule limitations and standards under the proposed regulatory options may 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[a] (pounds per year) | Estimated Changes in Pollutant Loadings[a] from Baseline (pounds per year) |
|---|---|---|
| Baseline | 1,126,905,000 | NA |
| Option 1 | 1,080,844,000 | 46,061,000 |
| Option 2 | 216,584,000 | 910,322,000 |
| Option 3 | 200,460,000 | 926,445,000 |
| Option 4 | 114,668,000 | 1,012,237,000 |

NA: Not applicable to the baseline

Note: Pollutant loadings and removals are rounded to three significant figures, so changes may match differences in the values shown due to independent rounding. See TDD for details (U.S. EPA, 2023d).

a. Industry-wide pollutant loadings reflect full implementation of effluent limitations and include bromide loadings in FGD wastewater under the maximum scenario (as well as bromide loadings in BA transport water). Values shown in this table do not account for generating unit retirements or conversions during the period of analysis which are estimated to reduce total industry loadings under the baseline and regulatory options.

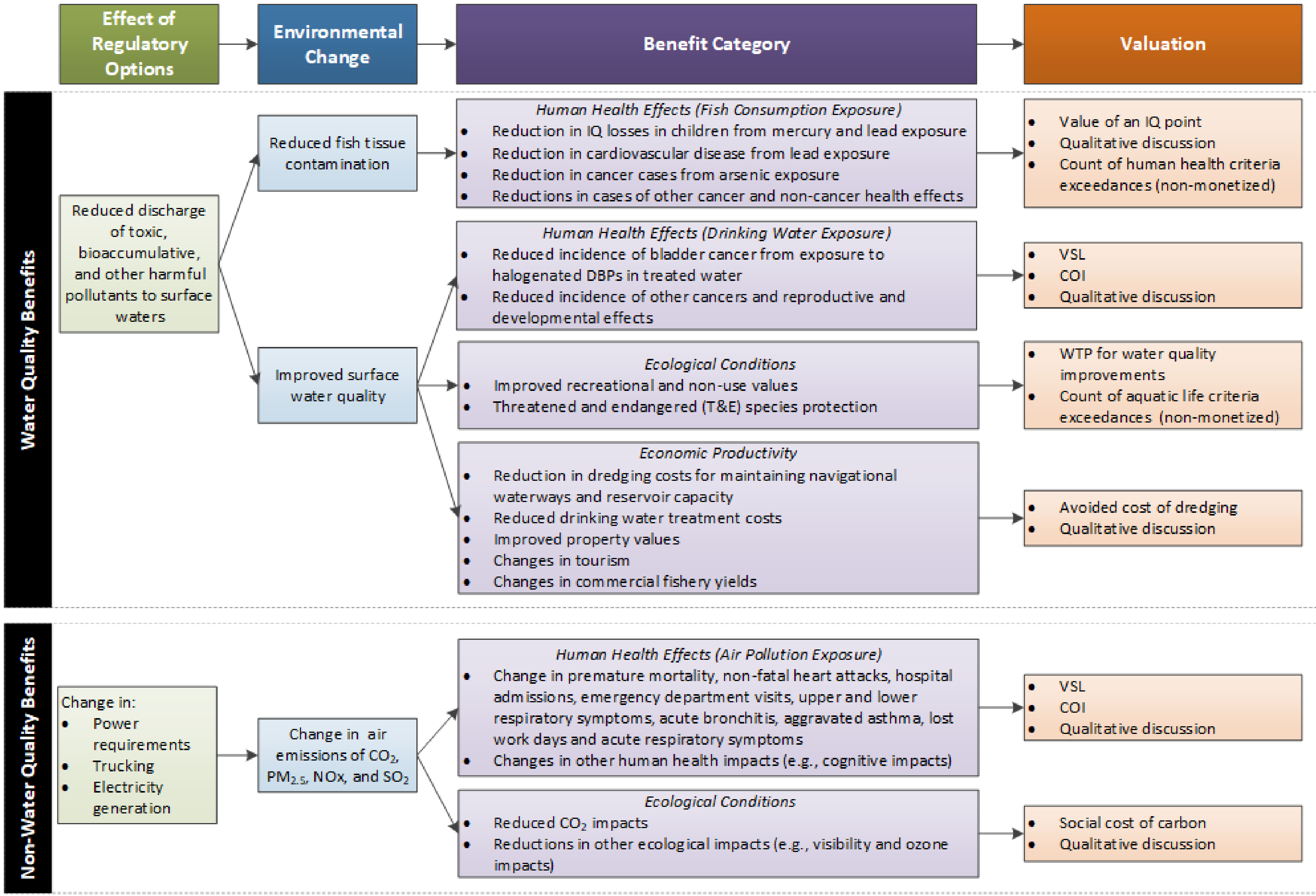
*Source: U.S. EPA Analysis, 2022*

In addition to water quality changes, effects of the regulatory options in comparison to the 2020 rule also include other effects of the implementation of control technologies and 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.

This chapter also provides a brief discussion of the effects of pollutants found in FGD wastewater, BA transport water, and CRL and 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 EA (U.S. EPA, 2023a).

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 the proposed rule, including human health effects, ecological effects, economic productivity, and changes in air pollution. 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 0 for the relevant benefit categories.

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




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

*Source: U.S. EPA Analysis, 2022.*

## 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, 2023a).

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, BA Transport Water and CRL 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, BA Transport Water and CRL 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 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 assumes 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 even where they are below the MCL.

EPA used a mass balance approach to estimate the changes in halogen (bromide) 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 some evidence of associations between adverse human health effects, including bladder cancer, and exposure to sufficient levels of halogenated disinfection byproducts in drinking water. For additional information on these topics, see the EA (U.S. EPA, 2023a). For the proposed rule, EPA quantitatively estimated the marginal 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.

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 regulatory option. This analysis is discussed in Section 4.3.2.3. EPA did not quantify or monetize benefits from reduced exposure to arsenic, lead, and thallium via drinking water due to the relatively small concentration changes in source waters downstream from steam electric plants. EPA however notes that coal ash effluents can make water more corrosive by increasing the conductivity of source waters used by downstream water systems and, as a result, increase lead leaching from water distribution infrastructure.

### *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:

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

The Agency evaluated potential changes in intellectual impairment, or intelligence quotient (IQ), resulting from changes in childhood and in-utero exposures to lead and mercury. 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. This is the same approach EPA used in its analysis of the 2019 Proposed Lead and Copper Rule (U.S. Environmental Protection Agency, 2019d).

During the 2020 rulemaking, 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, EPA again did not quantify, nor was it able to monetize, changes in health effects associated with exposure to these pollutants under the regulatory options. 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

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7 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.

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, 2013d; 2019d); effects to adults from exposure to lead such as cardiovascular diseases[8], decreased kidney function, reproductive effects, immunological effects, cancer and nervous system disorders (Aoki *et al.*, 2016; Chowdhury *et al.*, 2018; Clay *et al.*, 2021; Grossman & Slusky, 2019 Lanphear *et al.*, 2018; Navas-Acien, 2021; NTP, 2012; U.S. EPA, 2013d; 2019d;); 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, premature mortality, and others (Hollingsworth & Rudik, 2021 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,[9] 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; Ginsberg, 2012).

EPA recognizes that there may be 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, 2013d). However, data and resource limitations preclude a full analysis of such cumulative or synergistic effects. 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). While there are no existing methods to fully analyze and monetize these effects, EPA quantified some of these effects in the EA (U.S. Environmental Protection Agency, 2023a).

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 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 an approximate indication 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).

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8 Several systematic reviews of epidemiological studies found that lead exposure was positively associated with clinical cardiovascular outcomes, including cardiovascular mortality (Navas-Acien, 2021). However, the estimated changes in lead loadings and fish tissue concentrations are relatively small and thus unlikely to result in tangible benefits to adults. As shown in Section 2.1.2, the expected changes in blood lead levels are small even in sensitive populations (*i.e.*, children ages 0 to 7).

9 EPA is reviewing and evaluating new research on the relationship between cadmium exposure and kidney damage. Depending on the outcome of this evaluation, EPA may add a quantitative analysis for cadmium exposure changes to the final rule analysis.

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 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.

The composition of steam electric power plant wastewater depends on a variety of factors, such as fuel properties, 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, 2023a). 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, 2023a). 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 small relative to the changes estimated for the 2015 rule. Still, EPA expects the ecological impacts from the regulatory options could include improved habitat conditions 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 enhance ecosystem productivity in waterways and the health of resident species, including T&E species. Loading reductions projected under the regulatory options 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. Water quality improvements also have the potential to enhance recreational activities such as swimming, boating, fishing, and water skiing. Finally, the proposed 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.

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, BA transport water and CRL discharges, even when those individuals do not use or anticipate future use of such waters for recreational or other purposes, resulting in nonuse values. The sections below discuss selected categories of benefits associated with changes in ecosystem services (additional economic productivity benefits associated with changes in ecosystem services are discussed in section 2.3).

EPA's analysis is intended to isolate possible effects of the regulatory options on aquatic ecosystems and organisms, including T&E species; however, it does not account for 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. In cases where a NPDES permit would already provide for more stringent limits in the baseline than those that would be required under the proposed ELG, the improvements attributable to the proposed rule will be less than estimated in this analysis.

### *2.2.1 Changes in Surface Water Quality*

EPA quantified potential environmental impacts from the regulatory options by estimating in-waterway concentrations of FGD wastewater, BA transport water and CRL 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 changes in aquatic ecosystem conditions 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 EA 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 (U.S. EPA, 2023a).

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 (U.S. EPA, 2010a; OMB, 2003; Johnston, Boyle, *et al.*, 2017). 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; Johnston, Boyle, *et al.*, 2017). 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; Johnston *et al.*, 2021). 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" (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; Johnston *et al.*, 2021). Among benefit transfer methods, meta-analyses are often more accurate compared to other types of transfer approaches due to the data synthesis from multiple source studies (Rosenberger and Phipps, 2007; Johnston *et al.*, 2021). However, EPA acknowledges that there is still a potential for transfer errors (Shrestha *et al.*, 2007) and no transfer method is always superior (Johnston *et al.*, 2021).

EPA followed the same methodology used in analyzing the 2015 and 2020 rules (U.S. EPA, 2015a, 2020b) 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 under the regulatory options. The updates consisted of incorporating WTP estimates from more recent peer reviewed studies into EPA's existing econometric model.[10] 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 reducing discharges 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.[11]

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.

EPA was unable to monetize the proposed rule's effects on T&E species due to challenges in quantifying the response of T&E populations to changes in water quality. 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 (Subroy *et al.*, 2019; L. Richardson & Loomis, 2009). These studies, as summarized in Subroy *et al.* (2019), suggest that people attach economic value to protection of T&E species ranging from $15.5 per household (in 2021$) for Colorado pikeminnow to $152.8 (in 2021$) for lake sturgeon (both fish species).[12] 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 $12.5 million to $13.8 million (in 2021$) per year for Citrus County, Florida.[13] EPA's analysis does not account for the potential for the NPDES permit issuance process to establish more stringent site-specific controls to meet applicable water quality standards (*i.e.*, water quality-based effluent limits issued under Section 301(b)(1)(C)). The analysis may therefore overestimate any potential impacts to T&E species and associated 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, BA transport water and CRL 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

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10 See ICF (2022) for additional detail on updating the meta-analysis.

11 The U.S. 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

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

13 Range adjusted from $8.2 million to $9 million (in 2001$), using the CPI.

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, 2023a). 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 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, 2023a). 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 reducing discharges of pollutants to receiving reaches, the proposed rule may reduce the contamination of waterbody sediments, impacts to benthic organisms, and 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 regulatory options may have economic productivity effects stemming 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.[14] EPA estimated the changes in sediment deposition in reservoirs and navigational waterways. Chapter 9 discusses the associated benefits. Other benefit categories (*e.g.*, effects on drinking water treatment costs) are discussed qualitatively in the following sections.

### *2.3.1 Water Supply and Use*

The regulatory options are projected to reduce loadings of steam electric pollutants to surface waters relative to the baseline, and thus may affect the uses of these waters for drinking water supply and agriculture. EPA expects the effects to be relatively small, but the Agency is nevertheless considering engineering or treatment cost elasticity approaches to quantify avoided treatment costs from reduced halogens to inform understanding of these effects. Stakeholders with interest in this analysis are encouraged to provide additional information via public comments to EPA on how treatment costs vary with source water characteristics affected by coal ash effluents.

#### ***2.3.1.1 Drinking Water Treatment Costs***

The regulatory options have the potential to affect drinking water treatment costs (*e.g.*, for filtration and chemical treatment) by changing eutrophication levels and pollutant concentrations in source waters. Eutrophication, which is most commonly caused by an overabundance of nitrogen and phosphorus, is one of

[14] EPA estimated changes in the marketability of coal combustion ash as a benefit of the 2015 rule (U.S. EPA, 2015a). However, based on the baseline for this proposed rule which already requires ash to be handled dry, EPA does not expect incremental changes in the amount of ash handled dry vs. wet and benefits from increased marketing of coal combustion ash under any of the regulatory options.

the main causes of taste and odor impairment in drinking water and can have a major negative impact on public perceptions of drinking water safety. Additional treatment to address foul tastes and odors potentially increases 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[15] listed in Table 2-2 such as selenium and cyanide under either the baseline or the regulatory options (see Section 4.3.2.3 for details). EPA estimated no changes in MCL exceedances under the regulatory options. Treatment system operations do not generally respond to small incremental changes in source water quality for one pollutant or a small subset of pollutants. Accordingly, EPA did not conduct an analysis of changes in treatment costs incurred by public water systems (PWS) for this proposal given the relatively small changes in source water quality expected under the proposed rule and data gaps regarding effects on treatment system operations; however the Agency is considering possible approaches to calculate potential avoided drinking water treatment costs for the final rule.

Potential effects of the estimated changes in the levels of halogens downstream from steam electric power plant outfalls on drinking water treatment costs are currently uncertain in part because there are other environmental sources of halogens. In addition, 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, 2016c). 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. 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, 2005b, pages 7-19). Where 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 upgraded 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.[16] In some cases, operation and maintenance (O&M) costs may also be

15 Modeled drinking water concentrations reflect discharged pollutant loads from steam electric plants and from other facilities reporting to the Toxics Resources Inventory (TRI).

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

reduced. EPA did not have information on drinking water treatment costs at affected water systems or estimates of how costs of drinking water treatment for specific technologies vary with changes in halogen concentrations in source water. EPA is evaluating the application of engineering models or a halogen treatment cost elasticity approach to quantify avoided treatment costs from reduced source water halogens. Stakeholders are encouraged to provide information to help quantification of avoided drinking water treatment costs under the proposed rule. Aside from avoided treatment costs, the Agency assessed the changes in levels of halogens downstream from steam electric power plant outfalls and estimated health outcomes (avoided bladder cancer cases) associated with reduced DBP formation at downstream PWS (see Section 2.1.1 for a discussion of this benefit category and Chapter 4 for a discussion of the analysis).[17]

#### *2.3.1.2 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; Zhang *et al.*, 2018). For example, the same heavy metals found in oilfield produced waters (including barium, lead, and chromium) have been shown to accumulate in soil, plants, and oranges (Zhang *et al.*, 2018). Additionally, nutrients can increase eutrophication, 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 on how costs vary with relatively small estimated changes in water quality.

### *2.3.2 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 build up over time, reducing reservoir capacity and the useful life of reservoirs (Graf *et al.*, 2010; Palinkas & Russ, 2019; Rahmani *et al.*, 2018). Reservoir capacity has been diminishing over time. At a national scale, Randle *et al.* (2021) found that total reservoir storage capacity has dropped from a peak of 850 $Gm^3$ to 810 $Gm^3$. At a state scale, Rahmani *et al.* (2018) found that all 24 federally operated reservoirs in Kansas have collectively lost 17 percent of their original capacity with the highest single-reservoir loss of 45 percent. Dredging and other sediment management strategies can be used to reclaim capacity (Hargrove *et al.*, 2010; Miranda, 2017; Morris, 2020; Randle *et al.*, 2021; Winkelman. M.O. *et al.*, 2019).[18] 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 loads could result in a modest decrease in dredging costs in reservoirs under all regulatory options. See Chapter 9 for details.

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[17] Note that EPA's separate proposed rulemaking to regulate discharges of per- and polyfluoroalkyl substances in drinking water could result in implementation of drinking water treatment technologies that would reduce DBP levels during the analysis period.

[18] Other sedimentation management strategies may be used instead of, or in combination with, dredging. This includes reducing sediment yield through watershed management practices and routing sediments through or around reservoirs (Morris, 2020; Randle *et al.*, 2021).

### 2.3.3 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 (Clark *et al.*, 1985). Navigable 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. For example, the U.S. Army Corps of Engineers (USACE) maintains the Southwest Pass[19], the most highly utilized commercial deep-draft waterway in the country, and its rapid-onset shoaling has led to prolonged periods of draft restrictions for transiting vessels (*e.g*., reductions in the amount of cargo that can be transported per voyage). To counteract channel shoaling, the USACE has dredged an annual average 25 million cubic yards of sediment since 2015 (Hartman *et al.*, 2022). Dredging of navigable waterways can be costly. Following the previous example, total dredging expenditures in the Southwest Pass for the 2019 fiscal year amounted to $147.8 million (dredging expenditures between the 2015 and 2018 fiscal years ranged from $66.0 million to $65.4 million) (Hartman *et al.*, 2022).

EPA estimated that all regulatory options 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. Chapter 0 describes this analysis.

### 2.3.4 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 (Alkire *et al.*, 2020; Brame *et al.*, 2019; Beck *et al.*, 2001). In some cases, excessive pollutant loadings can lead to the closure of shellfish beds, thereby reducing shellfish harvests and causing economic losses from reduced harvests (Jin *et al.*, 2008; Trainer *et al.*, 2007; Islam & Masaru, 2004). 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 five steam electric power plants discharge BA transport water, FGD wastewater or CRL directly to the Great Lakes or to estuaries. Large distances and stream flows greatly reduce the relative impact of steam electric power plants discharging upstream from these systems. Although estimated decreases in annual average pollutant loads under the regulatory options may benefit local fish populations and commercial harvest, the overall effects to commercial fisheries arising from the regulatory options are difficult to quantify but are likely to be relatively small. Commercial species potentially affected by steam electric discharges account for approximately 1 percent of total landings value in the U.S.[20] Moreover, most

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19 This is the entrance channel for a port system which encompasses waters ranging from the Mississippi River in Baton Rouge, Louisiana to the Gulf of Mexico Project (Hartman *et al.*, 2022).

20 Based on U.S. commercial fisheries landing values in 2019. EPA obtained commercial fisheries landing data for areas that may be affected by steam electric discharges (Mississippi (Big Lake, connected to Biloxi Bay), Tampa, FL area (closest port to Hillsborough Bay), Lake Eerie, and Lake Michigan) and compared the potentially affected commercial fisheries landing value to

species of fish have numerous close substitutes. The economic literature suggests that when there are plentiful substitute fish products (*e.g.*, chicken is substitute for fish) 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.

### *2.3.5 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 (U.S. Bureau of Economic Analysis, 2021; Mojica & Fletcher, 2020; Highfill & Franks, 2019). 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 relatively small 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.

### *2.3.6 Property Values*

Discharges of pollutants may affect the aesthetic quality of water resources by 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, water turbidity, and other surface water characteristics. Several studies (*e.g.*, Austin, 2020; Bin & Czajkowski, 2013; K.J. Boyle *et al.*, 1999; Cassidy *et al.*, 2021; Gibbs *et al.*, 2002; Kuwayama *et al.*, 2022; Leggett & Bockstael, 2000; Liu *et al.*, 2017; M. R. Moore *et al.*, 2020; Netusil *et al.*, 2014; Tang *et al.*, 2018; Tuttle & Heintzelman, 2014; Patrick J. Walsh *et al.*, 2011; P.J. Walsh *et al.*, 2017; Wolf *et al.*, 2022) suggest that both waterfront and non-waterfront properties are more desirable when located near unpolluted water. For example, Austin (2020) finds that, in North Carolina, coal ash discharges' negative impacts to drinking water led to a 12 to 14 percent decline in sale price for homes within one mile of a coal ash pond after potential risks were made more salient by a state regulation. Therefore, the value of properties located in proximity to waters affected by steam electric plant discharges may increase due to reductions in discharges of FGD wastewater, BA transport water, and CRL.

EPA did not quantify or monetize the potential change in property values associated with the regulatory options. The magnitude of the effect on property values depends on many factors, including the number of housing units located in the vicinity of the affected waterbodies,[21] community characteristics (*e.g.*, residential density), housing stock (*e.g.*, single family or multiple family), and the effects of steam electric pollutants on the aesthetic quality of surface water. Given that changes in the aesthetic quality of surface waters (*e.g.*,

total U.S. commercial fisheries landing value (marine and Great Lakes). EPA obtained commercial fishery landing value for Mississippi and the U.S. from NOAA Fisheries (National Oceanic and Atmospheric Administration, 2022), for the Tampa area from the Florida Fish and Wildlife Conservation Commission (Florida Fish and Wildlife Conservation Commission, 2022), and for the Great Lakes from the Great Lakes Fishery Commission (Great Lakes Fishery Commission, 2022). EPA assumed that all fish species in Lake Eerie and Lake Michigan may be affected by steam electric discharges. For commercial fishery landings in Tampa and Mississippi, EPA removed deep sea fish species (*e.g.*, tuna, sharks, jacks, and octopus) from consideration of fish potentially affected by steam electric power plant discharges since they are unlikely to use the estuarine areas where discharges occur.

[21] In a review of 36 hedonic studies that focus on the impact of water quality on housing values, Guignet *et al.* (2021) note that some studies have detected property value impacts up to a mile away from impacted waterways.

clarity and odor) that may result from the relatively small changes in pollutant concentrations under the regulatory options is difficult to quantify, EPA did not estimate impacts of the proposed rule on property values. 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 proposed 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 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. The three mechanisms can produce changes in different directions. For example, increased energy use by power plant tend to increase air emissions associated with power generation, but those changes are relatively small when compared to the changes resulting from shifts in the electricity generation mix away from coal-fired generation and toward sources with lower emission factors. These shifts in generation mix result tend to reduce overall emissions at the national level, although the localized changes in air pollutant emissions may be positive or negative depending on which electricity generating units produce more or less electricity as a result of these shifts.

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 proposed rule (*i.e.*, Option 3). Electricity market analyses using IPM project that the proposed rule (Option 3) will expand on the baseline trend by shifting away from coal fired electric power generation toward generation from other energy sources, such as natural gas and renewables. Relative to the baseline, IPM projects coal-fired generation to decline as a result of the proposed rule. These changes are offset in part by an increase in natural gas generation, nuclear generation, and generation by renewables. Differences in emissions factors across energy sources generally results in net reductions in air emissions from electricity generating units across all modeled pollutants at the national level ($CO_2$, $SO_2$, $NO_X$, direct $PM_{2.5}$, $PM_{10}$, Hg, and hydrogen chloride (HCl)). Overall for the three mechanisms (auxiliary services, transportation, and market-level generation), EPA estimates net reductions in $CO_2$, $SO_2$, and $NO_X$ emissions as compared to the baseline at the national level. However, the distribution of the changes may result in localized increases even as the overall changes nationwide are decreases, and air emissions of some pollutants may increase in some years and decrease in others. See the RIA for details (U.S. EPA, 2023c).

$CO_2$ 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 social cost of carbon (SC-$CO_2$) to monetize the benefits of changes in $CO_2$ emissions as a result of the proposed 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[22] 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). 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 proposed 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 EA (U.S. EPA, 2023a). 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,[23] 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).

The proposed rule may also affect air quality if steam electric power plants alter their coal storing and handling practices, since Jha and Muller (2018) found that a 10 percent increase in coal stockpiles held by U.S. power plants results in a 0.09% increase in average $PM_{2.5}$ concentration levels within 25 miles of these plants. 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.

## 2.5 Summary of Benefits Categories

Table 2-3 summarizes the potential social welfare effects of the regulatory options analyzed for the proposed 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 reductions in some human health risks, use and non-use values from surface water quality improvements, reduced costs for dredging reservoirs and navigational waterways, and changes in air emissions. Other welfare effect categories, including changes in waters exceeding NRWQC, were quantified but not monetized. Although EPA was not able to quantify or monetize other welfare effects, including some other human health risks and impacts to commercial fisheries, those unquantified benefits may be relatively small compared to other monetized benefits.[24] EPA evaluated these effects qualitatively as discussed above in Sections 2.1 through 2.4.

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22 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.

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

24 The 2015 and 2020 rules, which are included in the baseline for this analysis, significantly reduced toxic pollutant and nutrient loadings, making additional reductions estimated for this proposed rule smaller, particularly when compared to the benefits that can be quantified and monetized.

**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 human health effects (*e.g.*, bladder cancer) associated with halogenated DBP exposure via drinking water | Changes in exposure to halogenated DBPs in drinking water | ✓ | ✓ | VSL and COI (Chapter 2) |
| IQ losses to children ages 0 to 7 | Changes in childhood exposure to lead from consumption of self-caught fish[a] | ✓ | ✓ | IQ point valuation (Chapter 5) |
| Need for specialized education | Changes in childhood exposure to lead from consumption of self-caught fish[a] | ✓ | ✓ | Qualitative discussion (Chapter 5) |
| Incidence of cardiovascular disease | Changes in exposure to lead from consumption of self-caught fish[a] | | | Qualitative discussion (Chapter 2) |
| IQ losses in infants | Changes in in-utero mercury exposure from maternal consumption of self-caught fish[a] | ✓ | ✓ | IQ point valuation (Chapter 5) |
| Incidence of cancer | Changes in exposure to arsenic from consumption of self-caught fish[a] | ✓ | ✓ | 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[b] | Changes in ambient water quality in receiving reaches | ✓ | ✓ | Benefit transfer (Chapter 6); Qualitative discussion (Chapter 2) |
| Water-based recreation[b] | Changes in swimming, fishing, boating, and near-water activities from water quality changes | | | |
| Aesthetics[b] | Changes in aesthetics from shifts in water clarity, color, odor, including nearby site amenities for residing, working, and traveling | | | |
| Non-use values[b] | Changes in existence, option, and bequest values from improved ecosystem health | | | |
| 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 0); Qualitative discussion (Chapter 2) |
| Water treatment costs for drinking water | Changes in quality of source water used for drinking | | | Qualitative discussion (Chapter 2) |
| Water treatment costs for irrigation and other agricultural uses | Changes in quality of source water used for 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 quality effects of coal stockpiles | Air quality effects of storing and handling coal at steam electric power plants | | | 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) |

a. Reductions in discharges of lead, mercury, and other toxic pollutants may reduce concentrations of these pollutants in open seas, thus reducing levels of pollutants in high trophic level fish harvested commercially. There are unquantified benefits associated with all of these end points for those who consume commercially harvested fish, but these benefits are very difficult to estimate.

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

*Source: U.S. EPA Analysis, 2022*

# 3 Water Quality Effects of Regulatory Options

Changes in the quality of surface waters, aquatic habitats and ecological functions under the regulatory options 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 (Option 1 through Option 4). The differences in 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 TDD (U.S. EPA, 2023d) and expand upon the analysis of immediate receiving waters described in the EA (U.S. EPA, 2023a) by estimating changes in both receiving and downstream reaches. The 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 163 steam electric power plants. 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 plants represented in the analysis, EPA estimated that 91 plants have non-zero pollutant discharges under the baseline or the regulatory options for any of the modeled wastestreams (FGD wastewater, BA transport water, or CRL). In the aggregate, the 91 plants discharge to 101 waterbodies (as categorized in NHDPlus), including lakes, rivers, and estuaries.[25] 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[26] for analysis of the fate and transport of steam electric power plant discharges (see Section 3.31.1). While six steam electric power plants discharge FGD wastewater, BA transport water or CRL to tidal reaches or the Great Lakes,[27] 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.[28] EPA did not quantify the water quality changes and

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25 Ten plants discharge waste streams to multiple (two or three) different receiving waters and one reach receives discharges from two separate plants.

26 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.

27 Three plants (Elm Road, JH Campbell, and Oak Creek) discharge non-zero loads to Lake Michigan, one plant (Monroe) discharges to Lake Erie, one plant (Big Bend) discharges to Hillsborough Bay, and one plant (Jack Watson) discharges via a canal to Big Lake, which is connected to Biloxi Bay. Because Great Lakes are complex waterbodies accurately modeling water quality impacts to the Great Lakes would require the application of complex models that was not feasible within this rulemaking.

28 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).

resulting benefits to these systems. Thus, EPA estimated changes in water quality downstream from 85 steam electric plants associated with a total of 96 receiving reaches.[29]

## 3.2 Changes in Pollutant Loadings

EPA estimated post-technology implementation pollutant loadings for each plant under the baseline and the regulatory options. The TDD details the methodology (U.S. EPA, 2023d). 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 discussed in Section 1.3.3, for the purpose of the economic impact and benefit analysis, EPA generally estimates that plants will implement control technologies to meet the applicable rule limitations and standards as their permits are renewed, and no later than December 31, 2029. This schedule recognizes that control technology implementation is likely to be staggered over time across the universe of steam electric power plants. 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 baseline 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 baseline loadings starting in 2025 through the applicable technology implementation year, applicable technology-based loadings corresponding to the analyzed scenario (baseline or regulatory option) for all years following a plant's modeled implementation year, and zero loadings following a unit's retirement or repowering (where applicable).

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 2025 through 2049:

- Period 1, which extends from 2025 through 2029, when the universe of plants would transition from current (baseline) treatment practices to practices that achieve the revised limits, and
- Period 2, which extends from 2030 through 2049 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 enables EPA to better represent the rule implementation and capture the transitional effects of the regulatory options. 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

[29] EPA analyzed a total of 163 plants that generate the wastestreams within the scope of the proposed rule. Not all these plants have costs and/or loads under the baseline or regulatory options, so while the modeling scope is all 163 plants, 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), leaving 85 plants for which EPA analyzed changes in downstream water quality.

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, 2023c), there is uncertainty in the exact timing of when individual steam electric power plants would be implementing technologies to meet the proposed 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.

### *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 2025-2029 represent a period of transition as plants implement treatment technologies to meet the revised limits under the regulatory options, whereas years 2030 through 2049 have steady state loadings that reflect implementation of technologies across all plants.[30]

Table 3-1 summarizes the average annual reductions during Period 1 and Period 2 in FGD wastewater, BA transport water, CRL, and total loads for selected pollutants that inform EPA's analysis of the benefits discussed in Chapters 4 through 7 and in Chapter 10. The regulatory options are estimated to result in either no change or in *reductions* in pollutant loadings under an option as compared to the baseline, with the reductions generally increasing as one progresses from Option 1 to Option 4. Further, loading reductions are largest during Period 2 when all steam electric plants have implemented the treatment technologies associated with the limits, as compared to the transition period represented by Period 1.

30 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 3-1: Annual Average Reductions in Total Pollutant Loading in Period 1 (2025-2029) and Period 2 (2030-2049) for Selected Pollutants in Steam Electric Power Plant Discharges, Compared to Baseline (lb/year)**

| Pollutant | Option 1[a] | | | | Option 2[a] | | | | Option 3[a] | | | | Option 4[a] | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | FGD | BA[b] | CRL[c] | Total[d] | FGD | BA[b] | CRL[c] | Total[d] | FGD | BA[b] | CRL[c] | Total[d] | FGD | BA[b] | CRL[c] | Total[d] |
| **Period 1 (2025-2029)** | | | | | | | | | | | | | | | | |
| Antimony | 0 | 47 | 0 | 47 | 45 | 47 | 0 | 92 | 45 | 93 | 0 | 138 | 48 | 95 | 0 | 143 |
| Arsenic | 0 | 25 | 210 | 235 | 62 | 25 | 210 | 297 | 62 | 50 | 210 | 321 | 65 | 51 | 210 | 326 |
| Barium | 0 | 288 | 0 | 288 | 1,490 | 288 | 0 | 1,780 | 1,490 | 569 | 0 | 2,060 | 1,570 | 584 | 0 | 2,160 |
| Beryllium | 0 | 0 | 0 | 0 | 14 | 0 | 0 | 14 | 14 | 0 | 0 | 14 | 15 | 0 | 0 | 15 |
| Boron | 0 | 14,400 | 0 | 14,400 | 2,380,000 | 14,400 | 0 | 2,400,000 | 2,380,000 | 28,400 | 0 | 2,410,000 | 2,520,000 | 29,200 | 0 | 2,550,000 |
| Bromide | 0 | 13,800 | 0 | 13,800 | 2,950,000 | 13,800 | 0 | 2,960,000 | 2,950,000 | 27,300 | 0 | 2,970,000 | 3,210,000 | 28,000 | 0 | 3,240,000 |
| Cadmium | 0 | 2 | 38 | 40 | 45 | 2 | 38 | 85 | 45 | 4 | 38 | 87 | 47 | 4 | 38 | 89 |
| Chromium | 0 | 14 | 13,600 | 13,600 | 68 | 14 | 13,600 | 13,700 | 68 | 27 | 13,600 | 13,700 | 72 | 28 | 13,600 | 13,700 |
| Copper | 0 | 11 | 25 | 35 | 40 | 11 | 25 | 75 | 40 | 21 | 25 | 86 | 42 | 22 | 25 | 89 |
| Cyanide | 0 | 0 | 0 | 0 | 10,100 | 0 | 0 | 10,100 | 10,100 | 0 | 0 | 10,100 | 10,600 | 0 | 0 | 10,600 |
| Lead | 0 | 28 | 0 | 28 | 36 | 28 | 0 | 64 | 36 | 56 | 0 | 92 | 38 | 57 | 0 | 95 |
| Manganese | 0 | 414 | 0 | 414 | 132,000 | 414 | 0 | 133,000 | 132,000 | 818 | 0 | 133,000 | 140,000 | 840 | 0 | 141,000 |
| Mercury | 0 | 0 | 6 | 6 | 1 | 0 | 6 | 7 | 1 | 1 | 6 | 7 | 1 | 1 | 6 | 7 |
| Nickel | 0 | 47 | 241 | 288 | 67 | 47 | 241 | 355 | 67 | 93 | 241 | 401 | 71 | 96 | 241 | 407 |
| TN | 0 | 7,140 | 0 | 7,140 | 79,500 | 7,140 | 0 | 86,600 | 79,500 | 14,100 | 0 | 93,600 | 84,100 | 14,500 | 0 | 98,500 |
| TP | 0 | 600 | 0 | 600 | 3,380 | 600 | 0 | 3,980 | 3,380 | 1,190 | 0 | 4,570 | 3,580 | 1,220 | 0 | 4,790 |
| Selenium | 0 | 33 | 0 | 33 | 61 | 33 | 0 | 94 | 61 | 66 | 0 | 126 | 64 | 67 | 0 | 131 |
| Thallium | 0 | 3 | 0 | 3 | 104 | 3 | 0 | 107 | 104 | 6 | 0 | 110 | 110 | 6 | 0 | 116 |
| TSS | 0 | 36,200 | 176,000 | 212,000 | 91,000 | 36,200 | 176,000 | 303,000 | 91,000 | 71,400 | 176,000 | 338,000 | 96,300 | 73,300 | 176,000 | 345,000 |
| Zinc | 0 | 92 | 1,230 | 1,320 | 212 | 92 | 1,230 | 1,530 | 212 | 181 | 1,230 | 1,620 | 224 | 186 | 1,230 | 1,640 |
| **Period 2 (2030-2049)** | | | | | | | | | | | | | | | | |
| Antimony | 0 | 235 | 0 | 235 | 98 | 235 | 0 | 333 | 98 | 327 | 0 | 426 | 103 | 328 | 0 | 431 |
| Arsenic | 0 | 126 | 583 | 709 | 135 | 126 | 583 | 844 | 135 | 176 | 583 | 894 | 142 | 176 | 583 | 901 |
| Barium | 0 | 1,440 | 0 | 1,440 | 3,240 | 1,440 | 0 | 4,680 | 3,240 | 2,010 | 0 | 5,250 | 3,410 | 2,010 | 0 | 5,420 |
| Beryllium | 0 | 0 | 0 | 0 | 31 | 0 | 0 | 31 | 31 | 0 | 0 | 31 | 33 | 0 | 0 | 33 |
| Boron | 0 | 71,900 | 0 | 71,900 | 5,190,000 | 71,900 | 0 | 5,260,000 | 5,190,000 | 100,000 | 0 | 5,290,000 | 5,460,000 | 100,000 | 0 | 5,560,000 |
| Bromide | 0 | 69,100 | 0 | 69,100 | 7,520,000 | 69,100 | 0 | 7,590,000 | 7,520,000 | 96,400 | 0 | 7,620,000 | 8,680,000 | 96,500 | 0 | 8,780,000 |
| Cadmium | 0 | 10 | 106 | 115 | 97 | 10 | 106 | 213 | 97 | 14 | 106 | 217 | 102 | 14 | 106 | 222 |
| Chromium | 0 | 69 | 37,700 | 37,800 | 149 | 69 | 37,700 | 38,000 | 149 | 96 | 37,700 | 38,000 | 156 | 96 | 37,700 | 38,000 |
| Copper | 0 | 53 | 68 | 121 | 87 | 53 | 68 | 209 | 87 | 75 | 68 | 230 | 92 | 75 | 68 | 234 |
| Cyanide | 0 | 0 | 0 | 0 | 21,900 | 0 | 0 | 21,900 | 21,900 | 0 | 0 | 21,900 | 23,000 | 0 | 0 | 23,000 |
| Lead | 0 | 141 | 0 | 141 | 78 | 141 | 0 | 219 | 78 | 197 | 0 | 275 | 82 | 197 | 0 | 279 |
| Manganese | 0 | 2,070 | 0 | 2,070 | 289,000 | 2,070 | 0 | 291,000 | 289,000 | 2,890 | 0 | 292,000 | 303,000 | 2,890 | 0 | 306,000 |
| Mercury | 0 | 1 | 17 | 18 | 1 | 1 | 17 | 19 | 1 | 2 | 17 | 20 | 1 | 2 | 17 | 20 |
| Nickel | 0 | 236 | 669 | 906 | 146 | 236 | 669 | 1,050 | 146 | 330 | 669 | 1,140 | 153 | 330 | 669 | 1,150 |
| TN | 0 | 35,700 | 0 | 35,700 | 173,000 | 35,700 | 0 | 209,000 | 173,000 | 49,800 | 0 | 223,000 | 182,000 | 49,800 | 0 | 232,000 |

**Table 3-1: Annual Average Reductions in Total Pollutant Loading in Period 1 (2025-2029) and Period 2 (2030-2049) for Selected Pollutants in Steam Electric Power Plant Discharges, Compared to Baseline (lb/year)**

| Pollutant | Option 1[a] | | | | Option 2[a] | | | | Option 3[a] | | | | Option 4[a] | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | FGD | BA[b] | CRL[c] | Total[d] | FGD | BA[b] | CRL[c] | Total[d] | FGD | BA[b] | CRL[c] | Total[d] | FGD | BA[b] | CRL[c] | Total[d] |
| TP | 0 | 3,000 | 0 | 3,000 | 7,370 | 3,000 | 0 | 10,400 | 7,370 | 4,180 | 0 | 11,600 | 7,750 | 4,190 | 0 | 11,900 |
| Selenium | 0 | 166 | 0 | 166 | 132 | 166 | 0 | 298 | 132 | 231 | 0 | 364 | 139 | 232 | 0 | 371 |
| Thallium | 0 | 15 | 0 | 15 | 227 | 15 | 0 | 242 | 227 | 21 | 0 | 248 | 238 | 21 | 0 | 260 |
| TSS | 0 | 181,000 | 488,000 | 669,000 | 198,000 | 181,000 | 488,000 | 868,000 | 198,000 | 252,000 | 488,000 | 939,000 | 209,000 | 252,000 | 488,000 | 949,000 |
| Zinc | 0 | 458 | 3,410 | 3,870 | 461 | 458 | 3,410 | 4,330 | 461 | 638 | 3,410 | 4,510 | 485 | 639 | 3,410 | 4,540 |

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

a. All numbers presented with three significant figures.

b. EPA did not estimate changes in ammonia, beryllium, and cyanide loadings associated with BA transport water.

c. EPA did not estimate changes in ammonia, beryllium, bromide, cyanide, lead, nitrogen, and phosphorus associated with CRL.

d. FGD, BA, and CRL loadings may not add up to the total due to independent rounding.

*Source: U.S. EPA Analysis, 2022.*

## 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. EPA used the same approach as used for the analysis of the 2020 rule and relied on 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 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 non-zero discharges to reaches represented in the NHD, which include the vast majority of plants within the scope of the rule; the models represent 85 plants out of the 91 plants with non-zero discharges under the baseline or regulatory options. As discussed in Section 3.1, EPA omitted six steam electric power plants that discharge non-zero loads 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.[31]

Following the approach used in the analysis of the 2015 and 2020 rules (U.S. EPA, 2015a, 2020b) to estimate pollutant concentrations, EPA also included loadings from major dischargers (in addition to the steam electric power plants) that reported to the Toxics Release Inventory (TRI). EPA used loadings reported to the TRI in 2019.[32] 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

31 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.

32 According to EPA TRI National Analysis, TRI releases to water reported in 2019 were approximately 3 percent higher, in the aggregate, than releases reported in 2018 (200.6 million pounds versus 194.3 million pounds), although longer trends generally show declines over time. See https://www.epa.gov/trinationalanalysis/water-releases for details.

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 and 2020 rules (U.S. EPA, 2015a, 2020b), 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 10 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 2019 TRI dischargers and that have chronic aquatic life-based NRWQC. Pollutants that meet these qualifications include arsenic, cadmium, hexavalent chromium, copper, lead, mercury, nickel, selenium, and zinc. See the EA for details on NRWQC (U.S. EPA, 2023a). 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 2020 rule analysis, the USGS National Water Information System (NWIS) provided concentration data from 2007-2017 for three parameters that are held constant between the baseline and regulatory options: 1) fecal coliform, 2) dissolved oxygen, and 3) biochemical oxygen demand (see Section 3.4.1.2).[33]

#### ***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.[34] Table 3-2 summarizes the number of reaches with estimated exceedances of NRWQC in the baseline and under the regulatory options. In Period 2, option 3 is estimated to eliminate all exceedances of chronic criteria

33 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/.

34 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 *EA* (U.S. EPA, 2023a).

for 5 reaches (of 40 reaches with at least one exceedance), and eliminate all exceedances of acute criteria for all four reaches with baseline exceedances.

**Table 3-2: 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 (2025-2029)** | | |
| Baseline | 42 | 4 |
| Option 1 | 42 | 2 |
| Option 2 | 42 | 2 |
| Option 3 | 40 | 2 |
| Option 4 | 40 | 2 |
| **Period 2 (2030-2049)** | | |
| Baseline | 40 | 4 |
| Option 1 | 40 | 2 |
| Option 2 | 35 | 0 |
| Option 3 | 35 | 0 |
| Option 4 | 35 | 0 |

*Source: U.S. EPA Analysis, 2022*

Refer to the EA for additional discussion of comparisons of receiving and downstream water pollutant concentrations to acute and chronic aquatic NRWQC (U.S. EPA, 2023a).

#### *3.4.1.2 Sources for Ambient Water Quality Data*

Following the approach used for the 2020 rule 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 geographical scope of the hydrologic unit (Hydrologic unit code (HUC8, HUC6, HUC4, and HUC2) to fill in all missing data.[35] 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

35 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 22), the next pair the subregion (approximately 245), the third pair the basin or accounting unit (approximately 405), and the fourth pair the subbasin, or cataloguing unit (approximately 2,400) (U.S. Geological Survey, 2007, 2022). Digits after the first eight offer more detailed information at the watershed and subwatershed levels. 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.

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 17,676 medium-resolution NHD reaches that are potentially affected by steam electric power plants under the baseline. Of these 17,676 NHD reaches, EPA estimated concentrations for 12,954 reaches affected by non-zero loadings from steam electric power plants. Table 3-3 summarizes the data sources used to estimate baseline and regulatory option values by water quality parameter.

**Table 3-3: 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, 2022.*

### *3.4.2 WQI Calculation*

EPA used the approach described in the BCA for the 2015 and 2020 rules (U.S. EPA, 2015a, 2020b) to estimate WQI values for each reach under the baseline and each option, and used the subindex curves for TN, TP, and SSC used for the 2020 rule[36] that reflect data from the most current SPARROW regional models (Ator, 2019; Hoos & 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 for each reach 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

[36] The 2015 WQI includes a subindex for TSS. For this analysis, EPA used the same curve for SSC used for the 2020 rule 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.

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.[37]

### *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 with a top value of 10 instead of the WQI scale with a top value of 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 9,358 NHD reaches using five WQI ranges (WQI < 25, 25≤WQI<45, 45≤WQI<50, 50≤WQI<70, and 70≤WQI) (Table 3-4). 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).[38]

**Table 3-4: 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 (2025-2029)** | | | | | |
| Unusable | WQI<25 | 0 | 0.0% | 0 | 0.0% |
| Suitable for Boating | 25≤WQI<45 | 221 | 2.4% | 293 | 3.0% |
| Suitable for Rough Fishing | 45≤WQI<50 | 384 | 4.1% | 296 | 3.0% |
| Suitable for Game Fishing | 50≤WQI<70 | 4,373 | 46.7% | 4,873 | 49.4% |
| Suitable for Swimming | 70≤WQI | 4,380 | 46.8% | 4,395 | 44.6% |
| **Total** | | **9,358** | **100.0%** | **9,858** | **100.0%** |
| **Period 2 (2030-2049)** | | | | | |
| Unusable | WQI<25 | 0 | 0.0% | 0 | 0.0% |
| Suitable for Boating | 25≤WQI<45 | 221 | 2.4% | 293 | 3.0% |
| Suitable for Rough Fishing | 45≤WQI<50 | 384 | 4.1% | 296 | 3.0% |
| Suitable for Game Fishing | 50≤WQI<70 | 4,373 | 46.7% | 4,873 | 49.4% |
| Suitable for Swimming | 70≤WQI | 4,380 | 46.8% | 4,395 | 44.6% |
| **Total** | | **9,358** | **100.0%** | **9,858** | **100.0%** |

*Source: U.S. EPA Analysis, 2022*

37 There are an estimated 17,676 NHD reaches on the downstream flow path of steam electric plant outfalls, of which 11,515 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 9,358 NHD reaches with the data needed to estimate WQI values.

38 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.

### *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 1.1, EPA estimated changes in ambient concentrations of TN, TP and SSC 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 3-5 presents water quality change ranges for the analyzed regulatory options under each analysis period.

**Table 3-5: Ranges of Estimated Water Quality Changes for Regulatory Options, Compared to Baseline**

| Options | Minimum ΔWQI | Maximum ΔWQI | 25th Percentile ΔWQI | Median ΔWQI | 75th Percentile ΔWQI | ΔWQI Interquartile Range |
|---|---|---|---|---|---|---|
| **Period 1 (2025-2029)** | | | | | | |
| Option 1 | 0 | 0.91 | 0 | $3.25\times10^{-7}$ | $1.74\times10^{-5}$ | $1.74\times10^{-5}$ |
| Option 2 | 0 | 0.91 | 0 | $7.13\times10^{-6}$ | $1.59\times10^{-4}$ | $1.59\times10^{-4}$ |
| Option 3 | 0 | 0.91 | $5.52\times10^{-6}$ | $5.11\times10^{-5}$ | $5.04\times10^{-4}$ | $4.98\times10^{-4}$ |
| Option 4 | 0 | 0.91 | $9.81\times10^{-6}$ | $6.30\times10^{-5}$ | $7.76\times10^{-4}$ | $7.66\times10^{-4}$ |
| **Period 2 (2030-2049)** | | | | | | |
| Option 1 | 0 | 1.17 | 0 | $2.78\times10^{-6}$ | $4.50\times10^{-5}$ | $4.50\times10^{-5}$ |
| Option 2 | 0 | 15.60 | $3.61\times10^{-7}$ | $3.70\times10^{-5}$ | $5.13\times10^{-4}$ | $5.13\times10^{-4}$ |
| Option 3 | 0 | 18.77 | $2.01\times10^{-5}$ | $1.61\times10^{-4}$ | $1.24\times10^{-3}$ | $1.22\times10^{-3}$ |
| Option 4 | 0 | 18.77 | $2.57\times10^{-5}$ | $1.91\times10^{-4}$ | $2.26\times10^{-3}$ | $2.23\times10^{-3}$ |

*Source: U.S. EPA Analysis, 2022*

## 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 3-6 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 TDD (U.S. EPA, 2023d).

**Table 3-6: 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. TRI releases are also reported by the facilities and could potentially suffer from misreporting or faulty estimation techniques. 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 or seasonal 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. Further, EPA acknowledges that the effect of steam electric power plant discharges on reach flows may vary seasonally due to low- and high-flow periods. |
| 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 2029) |

**Table 3-6: Limitations and Uncertainties in Estimating Water Quality Effects of Regulatory Options**

| Uncertainty/Limitation | Effect on Water Quality Effects Estimation | Notes |
|---|---|---|
| Changes in WQI reflect only reductions in toxics, nutrient, and suspended sediment 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. |
| 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 sediment 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

EPA expects that the changes in pollutant loadings from the regulatory options relative to the 2020 rule could affect several aspects of human health by changing bromide and other pollutant discharges to surface waters and, as a result, pollutant concentrations in the reaches that serve as sources of drinking water. The EA (U.S. EPA, 2023a) provides details on the health effects of steam electric pollutants.

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 changes in pollutant loadings from the regulatory options relative to the 2020 rule 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 EA presents background information regarding the potential impacts of halogen discharges on drinking water quality and human health (U.S. EPA, 2023a). Section 4.1 provides background information on trihalomethane precursor development. Sections 4.2 through 4.4 present EPA's analysis of human health effects from changes in bromide discharges. Section 4.5 summarizes potential impacts on source waters from changes in other pollutant discharges. Section 4.6 discusses uncertainty and limitations associated with the analysis presented in this chapter.

## 4.1 Background

FGD wastewater and BA transport water discharges contain variable quantities of bromide due to the natural presence of bromide in coal feedstock and from additions of halogens, including bromide-containing salts, and use of brominated activated carbon products to enhance air emissions control (Kolker *et al.*, 2012). Wastewater treatment technologies employed at steam electric power plants vary widely in their ability to remove bromide. A number of studies have documented elevated bromide levels in surface water due to steam electric power plant discharges (*e.g.*, Cornwell *et al.*, 2018; Good & VanBriesen, 2016, 2017; McTigue *et al.*, 2014; Ruhl *et al.*, 2012; States *et al.*, 2013; U.S. EPA, 2017c; 2019b) and have attributed measured increases in bromide levels to the increasing number of installed wet FGD devices at steam electric power plants. FGD wastewaters have been shown to contain relatively high levels of bromide relative to other industrial wastewaters. Modeling studies have sought to quantify the potential for drinking water sources to be affected by FGD wastewater discharges (Good & VanBriesen, 2019).

Bromide does not undergo significant physical *(e.g.*, sorption, volatilization), chemical or biological transformation in freshwater environments and is commonly used as a tracer in solute transport and mixing field studies. Surface waters transport bromide discharges to downstream drinking water treatment facility intakes where they are drawn into the treatment systems.

Although the bromide ion has a low degree of toxicity (World Health Organization, 2009), it can contribute to the formation of brominated DBPs during drinking water disinfection processes, including chlorination, chloramination, and ozonation. Bromate, a regulated DBP under the Safe Drinking Water Act (SDWA), forms when bromine reacts directly with ozone. Chlorine reacts with bromide to produce hypobromite ($BrO^-$), which reacts with organic matter to form brominated and mixed chloro-bromo DBPs, including three of the four regulated trihalomethanes[39] (THM4, also referred to as total trihalomethanes (TTHM) in this discussion) and two of the five regulated haloacetic acids[40] (HAA5). Additional unregulated brominated DBPs have been cited as an emerging class of water supply contaminants that can potentially pose health risks to humans (S. D. Richardson *et al.*, 2007; NTP, 2018; U.S. EPA, 2016c).

There is a substantial body of literature on trihalomethane precursor occurrence, trihalomethane formation mechanisms in drinking water treatment plants, and relationships between source water bromide levels and TTHM levels in treated drinking water. The formation of TTHM in a particular drinking water treatment plant is a function of several factors including chlorine, bromide, organic material, temperature, and pH levels as well as system residence times. There is also substantial evidence linking TTHM exposure to bladder cancer incidence (U.S. EPA, 2016c). Bromodichloromethane and bromoform are likely to be carcinogenic to humans by all exposure routes and there is evidence suggestive of dibromochloromethane's carcinogenicity (NTP, 2018; U.S. EPA, 2016c). The relationships between exposure to DBPs, specifically TTHMs and other halogenated compounds resulting from water chlorination, and bladder cancer are further discussed in Section 4.3.3.2 and U.S. EPA (2019a).

## 4.2 Overview of the Analysis

Figure 4-1 illustrates EPA's approach for quantifying and valuing the human health effects of altering bromide discharges from steam electric power plants. The analysis entails estimating in-stream changes in bromide levels between conditions under the baseline and each of the four regulatory options (Step 1); estimating the change in source water bromide levels and corresponding changes in TTHM concentrations in treated water supplies (Step 2); relating these estimated changes to changes in exposure and the subsequent changes in the incidence of bladder cancers[41] in the exposed population (Step 3); and estimating the associated monetary value of benefits (Step 4). This approach was implemented in EPA's 2019 proposed rule (U.S. EPA, 2019a) and relies on findings from a peer-reviewed paper by Regli *et al.* (2015) that built on the approach taken in the Stage 2 Disinfectants and Disinfection Byproduct Rule (DBPR) (U.S. EPA, 2005b) to derive a slope factor to relate changes in lifetime bladder cancer risk to changes in TTHM exposure. This analysis also incorporates recent National Cancer Institute's Surveillance, Epidemiology, and End Results (SEER) program data to model incidence of bladder cancers by age and sex, cancer stage, changes in lifetime cancer risk attributable to the proposed rule options, and survival outcomes. The life-table modeling approach used by EPA to estimate changes in health outcomes is a widely used method in public health, insurance, medical research, and other studies and was used for analysis of lead-associated health effects in the 2015 rule. The main advantage of this approach is that it allows for explicitly accounting for age and cancer stage-specific patterns in cancer outcomes, as well as for other causes of mortality in the affected population.

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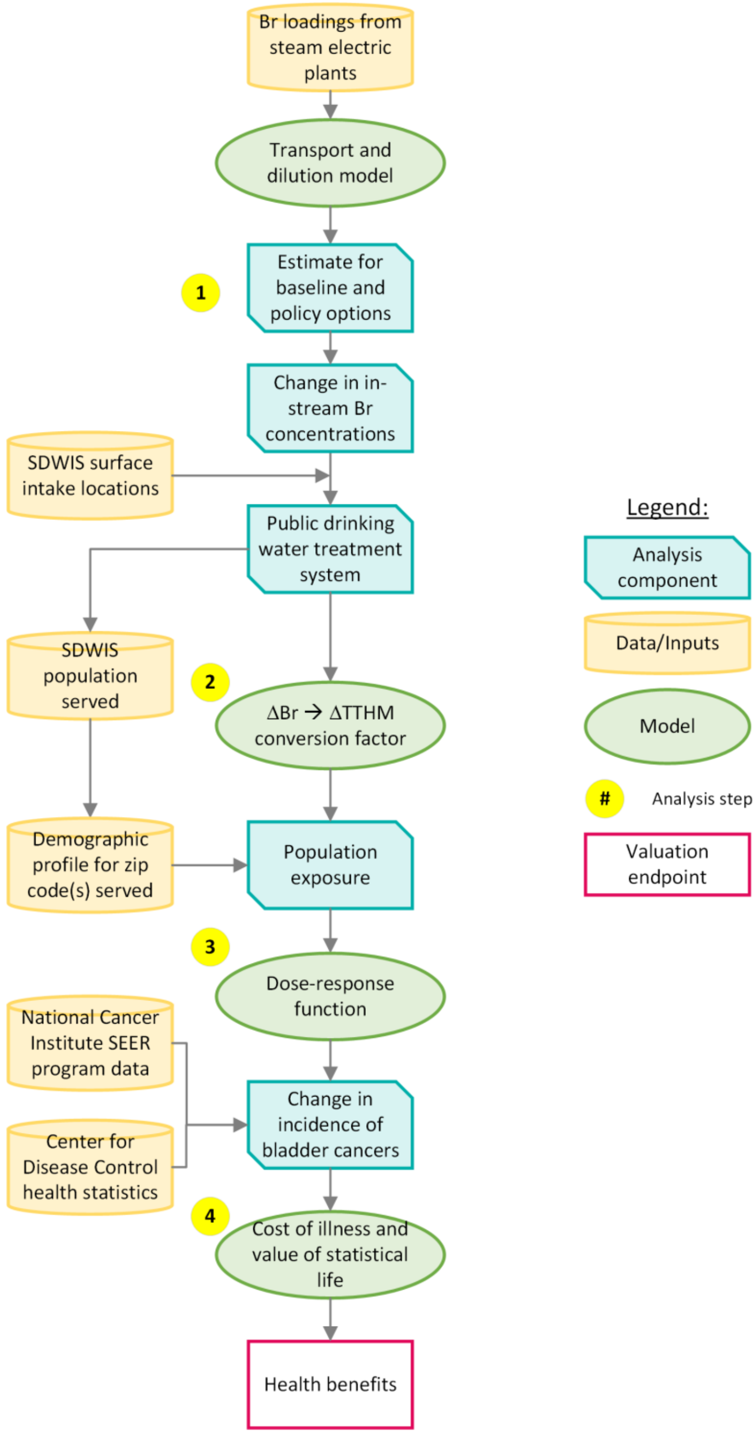
39 The four regulated trihalomethanes are bromodichloromethane, bromoform, chloroform, and dibromochloromethane.

40 The five regulated haloacetic acids are dibromoacetic acid, dichloroacetic acid, monobromoacetic acid, monochloroacetic acid, and trichloroacetic acid.

41 Regli *et al.* (2015) estimated the additional lifetime risk from a 1 µg/L increase in TTHM. This relationship holds over the TTHM range expected for systems in compliance with the Stage 2 Disinfectants and Disinfection Byproduct Rule.

**Figure 4-1: Overview of Analysis of Estimated Human Health Benefits of Reducing Bromide Discharges.**




*Source: U.S. EPA Analysis, 2022.*

## 4.3 Estimates of Changes in Halogen Concentrations in Source Water

For the proposed rule, EPA estimated the change in halogen levels in the source water for PWS that have intakes downstream from steam electric power plants.[42] Halogens such as bromide 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, and in turn the total counts of these health effects.

In this section, the Agency presents the number of PWS with modeled changes in bromide 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 levels.

### *4.3.1 Step 1: Modeling Bromide Concentrations in Surface Water*

EPA estimated steam electric power plant-level bromide loadings associated with FGD wastewater and BA transport water for the baseline and the regulatory options.[43] This chapter presents EPA's best estimate of changes in bromide 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 47 steam electric power plants that EPA estimated have non-zero bromide loads (*i.e.*, discharge FGD wastewater and/or BA transport water) under the baseline or regulatory options. EPA first estimated the annual average bromide loads in Period 1 and Period 2 (see Section 3.2.1). EPA then estimated concentrations in the receiving reach and each downstream reach in Period 1 and Period 2, using conservation of mass principles, until the load reaches the network terminus (*e.g.*, Great Lake, estuary).[44] EPA summed individual contributions from all plants to estimate total in-stream concentrations under the baseline and the regulatory options in Period 1 and Period 2. Finally, EPA estimated the change in bromide concentrations in each reach as the difference between each regulatory option and the baseline. This change is not dependent on bromide contributions from other sources (*e.g.*, receiving waterbody background levels).

### *4.3.2 Step 2: Modeling Changes in Trihalomethanes in Treated Water Supplies*

#### ***4.3.2.1 Affected Public Water Systems***

For the proposed 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

42 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)

43 EPA did not estimate bromide loadings associated with CRL discharges.

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

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).

EPA's Safe Drinking Water Information System (SDWIS) database[45] provides the latitude and longitude of surface water facilities[46], 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.[47] *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 are categorized as "active" and "permanent" in SDWIS. This subset of facilities corresponds to PWS that are more likely to be affected by upstream bromide 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.[48] 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 either directly or indirectly affected systems.

Table 4-1 summarizes the intakes, PWS, and populations potentially affected by steam electric power plant discharges.[49] In this analysis, the average distance from the steam electric power plant discharge point to the drinking water treatment plant intake is 392 miles and approximately 17 percent of the intakes are located within 50 miles of a steam electric power plant outfall. A subset of these PWS is downstream of FGD wastewater and BA transport water discharges containing bromide,[50] specifically 485 reaches have intakes used by 722 PWS serving a total of 27.8 million people.

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45 EPA used intake locations and PWS data as of April 2021, which reflects the first quarter report for 2021. 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/.

46 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.

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

48 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.

49 Four PWS may be both directly and indirectly affected.

50 Note that when plants retire, bromide may still be present in CRL. The present analysis considers bromide discharges from FGD wastewater and BA transport water only.

**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] | 244 | 370 | 262 | 16.4 |
| Indirect | Not applicable | Not applicable | 690 | 25.6 |
| **Total** | **244** | **370** | **952** | **42.0** |

a. Includes four 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, 2022*

#### *4.3.2.2 System-Level Changes in Bromide Concentrations in Source Water*

EPA estimated the change in bromide 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 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 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 discharges, the system-level changes in bromide concentration at the PWS would equal the estimated change in bromide 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 concentrations at these PWS are an average of the estimated changes in bromide 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 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 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 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 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 four PWS classified as both directly and indirectly affected by steam electric power plant bromide discharges, EPA assessed the total change in bromide 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 3-1). During Periods 1 and 2, all options show either reductions or no changes in bromide concentrations for all source waters and PWS. For all options, the magnitude and scope (the number of reaches, PWS, and population served) of the bromide reductions are larger during Period 2 than during Period 1.

**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 | |
|---|---|---|---|---|---|---|
| | Reduction ΔBr | No ΔBr (ΔBr = 0) | Reduction ΔBr | No ΔBr (ΔBr = 0) | Reduction ΔBr | No ΔBr (ΔBr = 0) |
| **Period 1 (2025-2029)** | | | | | | |
| **Option 1** | | | | | | |
| 0 to 10 | 4 | 217 | 11 | 780 | 445,998 | 37,906,912 |
| **Option 2** | | | | | | |
| 0 to 10 | 86 | 135 | 311 | 480 | 7,152,912 | 31,199,998 |
| **Option 3** | | | | | | |
| 0 to 10 | 140 | 81 | 565 | 226 | 25,187,987 | 13,164,923 |
| **Option 4** | | | | | | |
| 0 to 10 | 156 | 64 | 606 | 183 | 26,964,720 | 11,303,045 |
| 10 to 30 | 1 | 0 | 2 | 0 | 85,145 | 0 |
| **Period 2 (2030-2049)** | | | | | | |
| **Option 1** | | | | | | |
| 0 to 10 | 4 | 217 | 11 | 780 | 445,998 | 37,906,912 |
| **Option 2** | | | | | | |
| 0 to 10 | 87 | 129 | 278 | 463 | 6,425,440 | 30,953,816 |
| 10 to 30 | 4 | 0 | 43 | 0 | 820,436 | 0 |
| 30 to 50 | 1 | 0 | 7 | 0 | 153,218 | 0 |
| >50 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Option 3** | | | | | | |
| 0 to 10 | 148 | 68 | 541 | 197 | 29,454,222 | 7,909,016 |
| 10 to 30 | 4 | 0 | 46 | 0 | 836,454 | 0 |
| 30 to 50 | 1 | 0 | 7 | 0 | 153,218 | 0 |
| >50 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Option 4** | | | | | | |
| 0 to 10 | 163 | 51 | 580 | 154 | 31,227,763 | 6,047,138 |
| 10 to 30 | 5 | 0 | 48 | 0 | 839,646 | 0 |
| 30 to 50 | 1 | 0 | 7 | 0 | 153,218 | 0 |
| 50 to 75 | 0 | 0 | 0 | 0 | 0 | 0 |
| >75 | 1 | 0 | 2 | 0 | 85,145 | 0 |

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

*Source: U.S. EPA Analysis, 2022.*

### *4.3.2.3 Changes in TTHM Concentration in Treated Water Supplies*

The prior step provides the estimated PWS-level change in bromide concentration in the blend of source waters used by a given system. The step described in this section provides the estimated PWS-level change in TTHM concentration associated with this change in bromide concentration.

Regli *et al.* (2015) applied the Surface Water Analytical Tool (SWAT) version 1.1, which models TTHM concentrations in drinking water treatment plants as a function of precursor levels, source water quality (*e.g.*, bromide and organic material levels), water temperature, treatment processes (*e.g.*, pH, residence time), and disinfectant dose (*e.g.*, chlorine levels) to predict the distribution of changes in TTHM concentrations in finished water associated with defined increments of changes in bromide concentration in source waters. That study estimated the distribution of increments of change in TTHM concentration for a subset of the population of PWS characterized in the 1997-1998 Information Collection Rule (ICR) dataset. Table 4-3 summarizes the results from the Regli *et al.* (2015) analysis.

**Table 4-3: Estimated Increments of Change in TTHM Levels (µg/L) as a Function of Change in Bromide Levels (µg/L)**

| Change in bromide concentration (µg/L) | Change in TTHM concentration (µg/L) | | | | | |
|---|---|---|---|---|---|---|
| | Minimum | 5th Percentile | Median | Mean | 95th Percentile | Maximum |
| 10 | 0.0 | 0.1 | 1.1 | 1.3 | 3.4 | 10.1 |
| 30 | 0.0 | 0.3 | 2.6 | 3.2 | 8.3 | 23.7 |
| 50 | 0.0 | 0.5 | 3.7 | 4.6 | 11.6 | 33.2 |
| 75 | 0.0 | 0.6 | 4.9 | 6.0 | 14.8 | 42.1 |
| 100 | 0.0 | 0.8 | 5.8 | 7.1 | 17.5 | 49.3 |

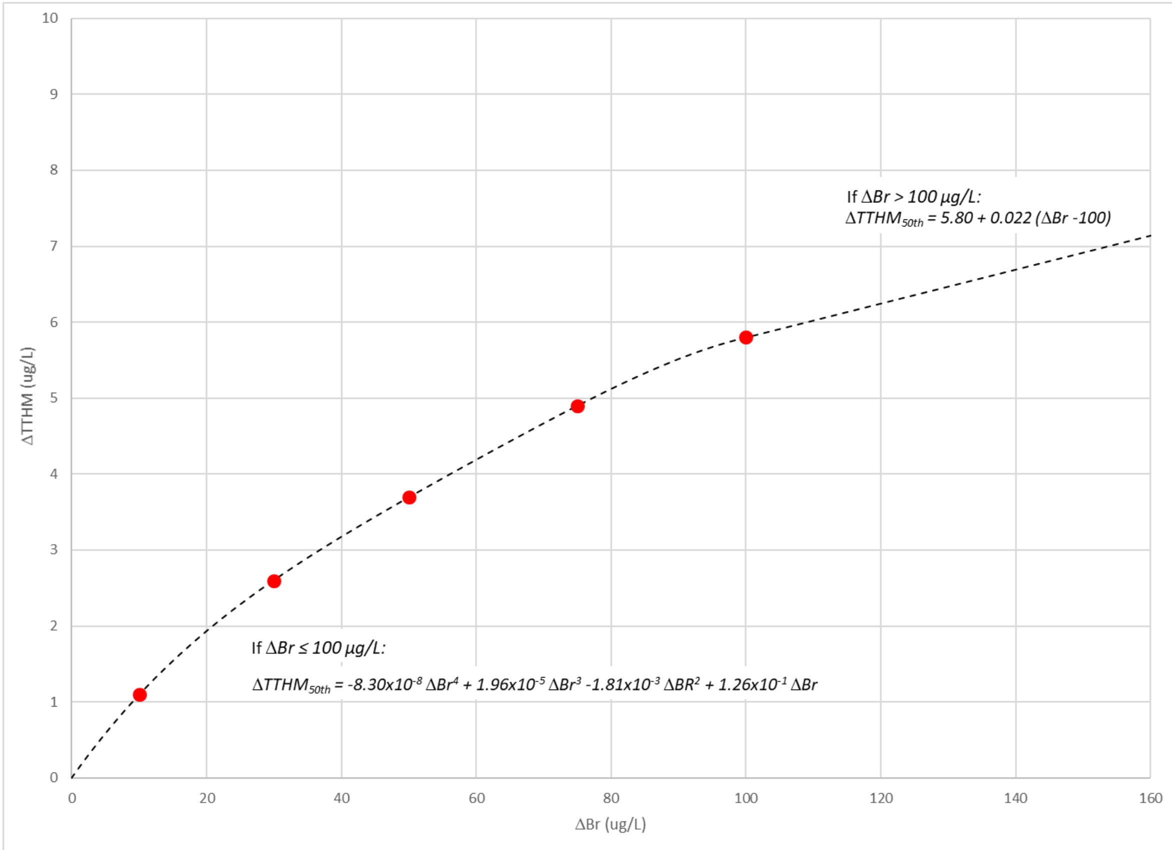
*Source: Regli et al. (2015), Table 2.*

For this analysis, EPA used the results from Regli *et al.* (2015) to predict TTHM concentration changes for each water treatment plant with changes in bromide concentrations in their source water due to the regulatory options. Figure 4-2 shows the relationship (dashed line) between the change in bromide concentration and the change in TTHM concentration based on fitting a polynomial curve through the median estimates from Table 4-3 (circular markers). EPA used the equation of the best-fit curve[51] to estimate changes in TTHM concentration as a function of changes in bromide concentration within the bromide concentration range presented in Regli *et al.* (2015) (0 to 100 µg/L). Estimates of TTHM concentration changes presented in the remainder of this section reflect median changes from Regli *et al.* (2015).[52] EPA evaluated the sensitivity of benefits estimates to the relationship between changes in bromide and changes in TTHM using the 5th and 95th percentile estimates in Table 4-3 in the 2019 proposed rule (U.S. EPA, 2019a).

51 The polynomial curve fits observations in Table 4-3 with residuals of zero over the range of observations.

52 While Regli *et al.* (2015) show similar mean and median changes in TTHM concentrations across the range of changes in bromide concentrations, EPA used the median to minimize potential influence of outlier values or skew in the distribution. Mean changes in TTHM for changes in bromide levels of 10, 30, 50, 75, and 100 µg/L were 1.3, 3.2, 4.6, 6.0 and 7.1 µg/L, respectively. Median changes in TTHM for changes in bromide levels of 10, 30, 50, 75, and 100 µg/L were 1.1, 2.6, 3.7, 4.9, and 5.8 µg/L, respectively.

**Figure 4-2: Modeled Relationship between Changes in Bromide Concentration and Changes in TTHM Concentrations based on Median Values in Regli *et al.* (2015).**




*Source: U.S. EPA Analysis, 2022, based on Regli et al. (2015).*

Table 4-4 shows the distribution of modeled absolute changes in TTHM concentrations and the potentially exposed populations under each of the regulatory options. As shown in the table, the magnitude of estimated bromide concentration changes is generally less than 10 µg/L, corresponding to estimated changes in TTHM concentrations of less than 1.1 µg/L. Compared to the baseline, all options are estimated to reduce TTHM concentrations in treated water.

**Table 4-4: Distribution of Estimated Changes in TTHM Concentration by the Number of PWS and Population Served**

| Absolute ΔBr range[a] (µg/L) | Absolute ΔTTHM range[a] (µg/L) | Number of PWS[b] | Total population served (million people)[c] |
|---|---|---|---|
| **Period 1 (2025-2029)** | | | |
| **Option 1** | | | |
| >0 to 10 | 0.10 to 0.14 | 11 | 0.45 |
| **Option 2** | | | |
| >0 to 10 | 0.01 to 0.89 | 311 | 7.15 |
| **Option 3** | | | |
| >0 to 10 | 0.00 to 0.88 | 565 | 25.19 |
| **Option 4** | | | |
| >0 to 10 | 0.00 to 0.89 | 606 | 26.97 |
| 10 to 30 | 1.62 to 1.62 | 2 | 0.09 |

**Table 4-4: Distribution of Estimated Changes in TTHM Concentration by the Number of PWS and Population Served**

| Absolute ΔBr range[a] (μg/L) | Absolute ΔTTHM range[a] (μg/L) | Number of PWS[b] | Total population served (million people)[c] |
|---|---|---|---|
| **Period 2 (2030-2049)** | | | |
| **Option 1** | | | |
| >0 to 10 | 0.49 to 0.66 | 11 | 0.45 |
| **Option 2** | | | |
| >0 to 10 | 0.02 to 1.09 | 278 | 6.43 |
| 10 to 30 | 1.10 to 1.90 | 43 | 0.82 |
| 30 to 50 | 3.06 to 3.06 | 7 | 0.15 |
| **Option 3** | | | |
| >0 to 10 | 0.00 to 1.08 | 541 | 29.45 |
| 10 to 30 | 1.10 to 1.91 | 46 | 0.84 |
| 30 to 50 | 3.06 to 3.06 | 7 | 0.15 |
| **Option 4** | | | |
| >0 to 10 | 0.00 to 1.08 | 580 | 31.23 |
| 10 to 30 | 1.10 to 1.91 | 48 | 0.84 |
| 30 to 50 | 3.06 to 3.06 | 7 | 0.15 |
| 50 to 75 | -- | -- | -- |
| >75 | 5.12 to 5.12 | 2 | 0.09 |

--: No data (*i.e.*, there are no observations within the specified ΔBr range)
*Source: U.S. EPA Analysis, 2022.*

### 4.3.3 Step 3: Quantifying Population Exposure and Health Effects

EPA used the following steps to quantify changes in human health resulting from changes in TTHM levels in drinking water supplies:

- Characterize the exposed populations;
- Estimate changes in individual health risk; and
- Quantify the changes in adverse health outcomes.

#### 4.3.3.1 Exposed Populations

The exposed populations consist of people served by each affected PWS. SDWIS provides the total population served by each PWS and identifies the ZIP codes constituting the PWS service area. EPA used ZIP codes information to determine the demographic characteristics of the population served.[53] Some PWS-ZIP code assignments are absent from the SDWIS 2021 Quarter 3 dataset (U.S. EPA, 2021c). In these cases, EPA relied on ZIP code assignments from the fourth Unregulated Contaminant Monitoring database (U.S. EPA, 2016a) to supplement PWS-ZIP code assignments.

53 EPA used ZIP codes instead of counties for the 2019 proposed rule and 2020 final rule analyses to enable a more accurate characterization of the demographic and socioeconomic characteristics of the service areas.

EPA used ZIP code-level data from the 2019 American Community Survey (U.S. Census Bureau, 2019) to distribute the total population served by each PWS by age group to model health effects as described in Section 4.3.3.3.

EPA assumed that all individuals served by a given PWS are exposed to the same modeled changes in TTHM levels for the PWS, *i.e.*, there are no differences in TTHM concentrations in different parts of the water distribution system.

#### *4.3.3.2 Health Impact Function*

The relationship between exposure to DBPs, specifically trihalomethanes and other halogenated compounds resulting from water chlorination, and bladder cancer has been the subject of multiple epidemiological studies (Cantor *et al.*, 2010; U.S. EPA, 2005b; NTP, 2018), a meta-analysis (Villanueva *et al.*, 2003; Costet *et al.*, 2011), and pooled analysis (Villanueva *et al.*, 2004). The relationship between trihalomethane levels and bladder cancer in the Villanueva *et al.* (2004) study was used to support the benefits analysis for EPA's Stage 2 DBP Rule[54] which specifically aimed to reduce the potential health risks from DBPs (U.S. EPA, 2005b).

Regli *et al.* (2015) conducted an analysis of potential bladder cancer risks associated with increased bromide levels in surface source water. To estimate risks associated with modeled TTHM levels, they built on the approach taken in EPA's Stage 2 DBP Rule, *i.e.*, deriving a slope factor from the pooled analysis of Villanueva *et al.* (2004). They showed that the overall pooled exposure-response relationship for TTHM is linear over a range of relevant doses. The linear relationship predicted an incremental lifetime cancer risk of 1 in ten thousand exposed individuals ($10^{-4}$) per 1 µg/L increase in TTHM. The linear model proposed by Regli *et al.* (2015) provides a basis for estimating the dose-response relationship associated with changes in TTHM levels estimated for the regulatory options. The linear slope factor enables estimates of the total number of cancer cases associated with lifetime exposures to different TTHM levels.

EPA used the relationship estimated by Regli *et al.* (2015) to model the impact of changes in TTHM concentration in treated water on the lifetime bladder cancer risk:

**Equation 4-1.** $$O(x) = O(0) \cdot \exp\,(0.00427x),$$

where $O(x)$ are the odds of lifetime bladder cancer incidence for an individual exposed to a lifetime average TTHM concentration in residential water supply of $x$ µg/L and $O(0)$ are the odds of lifetime bladder cancer in the absence of exposure to TTHM in residential water supply. The log-linear relationship (Equation 4-1) has the advantage of being independent from the baseline TTHM exposure level, which is highly uncertain for most affected individuals due to lack of historical data.

#### *4.3.3.3 Health Risk Model and Data Sources*

EPA estimated changes in lifetime bladder cancer cases due to estimated changes in lifetime TTHM exposure using a dynamic microsimulation model that estimates affected population life tables under different exposure conditions. Life table approaches are standard among practitioners in demography and risk sciences and provide a flexible method for estimating the probability and timing of health impacts during a defined period

[54] See DBP Rule documentation at https://www.epa.gov/dwreginfo/stage-1-and-stage-2-disinfectants-and-disinfection-byproducts-rules

(Miller & Hurley, 2003; Rockett, 2010).[55] In this application, the life table approach estimates age-specific changes in bladder cancer probability and models subsequent bladder cancer mortality, which is highly dependent on the age at the time of diagnosis. This age-specific cancer probability addresses variability in age-specific life expectancy across the population alive at the time the change occurs. This model allows for quantification of relatively complex policy scenarios, including those that involve variable contaminant level changes over time.

For this analysis, EPA assumed that the population affected by estimated changes in bromide discharges from steam electric power plants is exposed to baseline TTHM levels prior to implementation of the regulatory options – *i.e.*, prior to 2025 – and to alternative TTHM levels from 2025 through 2049. As described in Section 1.3.3, the period of analysis is based on the approximate life span of the longest-lived compliance technology for any steam electric power plant (20 or more years) and the final year of implementation (2029). The change in TTHM exposure affects the risk of developing bladder cancer beyond this period, however, because the majority of cancer cases manifest during the latter half of the average individual life span (Hrudey *et al.*, 2015). To capture these effects while being consistent with the framework of evaluating costs and benefits incurred from 2025-2049, EPA modeled changes in health outcomes resulting from changes in exposure in 2025-2049. Since changes in cancer incidence occur long after exposure, EPA modeled associated changes in cancer incidence through 2125, though only for the changes attributable to changed exposures in the 2025-2049 timeframe.

Lifetime health risk model data sources, detailed in Table 4-5 (next page), include EPA SDWIS and UCMR 4, ACS 2019 (U.S. Census Bureau, 2019), the Surveillance, Epidemiology, and End Results (SEER) program database (National Cancer Institute), and the Center for Disease Control (CDC) National Center for Health Statistics.

[55] The EPA has used life table approaches to estimate health risks associated with radon in homes, formaldehyde exposure, and Superfund and RCRA site chemicals exposure, among others (Pawel & Puskin, 2004; Munns & Mitro, 2006; National Research Council, 2011).

**Table 4-5: Summary of Data Sources Used in Lifetime Health Risk Model**

| Data element | Modeled variability | Data source | Notes |
|---|---|---|---|
| Number of persons in the affected population in 2025 | Age: 1-year groups (ages 0 to 100)<br>Sex: males, females<br>Location: zip code for PWS service area from SDWIS[a] and the fourth Unregulated Contaminant Monitoring Rule (UCMR 4) database[b] | 2019 American Community Survey (ACS) (data on age- and sex-specific zip code-level population [U.S. Census Bureau, 2019 and age- and sex-specific population projections from Woods & Poole Economics Inc. (2021). | ACS data were in 5-year age groups. EPA assumed uniform distribution within each age interval to represent data as 1-year age groups. EPA then grew the age- and sex-specific zip code-level population data to the beginning of the analysis period (2025) using corresponding county-specific growth rates calculated using the Woods & Poole Economics Inc. (2021) complete demographic database. EPA then computed relevant age- and sex- population shares and used them to distribute location-specific affected population within each zip code |
| Bladder cancer incidence rate (IR) per 100,000 persons | Age at diagnosis: 1-year groups (ages 0 to 100)<br>Sex: males, females | SEER 21 (Surveillance Research Program - National Cancer Institute, 2020b)[c] | Distinct SEER 21 IR data were available for ages 0, 1-4, 5-9, 10-14, 15-19, 20-24, 25-29, 30-34, 35-39, 40-44, 45-49, 50-54, 55-59, 60-64, 65-69, 70-74, 75-79, 80-84, 85+. EPA assumed that the same IR applies to all ages within each age group. EPA assumed that non-Hispanic Black IRs can be approximated by Black IRs. EPA assumed that non-Hispanic Other IRs can be approximated by all race IRs. |
| General population mortality rate | Age: 1-year groups (ages 0 to 100)<br>Sex: males, females | Center for Disease Control (CDC)/National Center for Health Statistics (NCHS) United States Life Tables, 2017 | EPA used race/ethnicity-, age- and sex-specific probabilities of dying within the integer age intervals. EPA assumed that non-Hispanic Other data can be approximated by all race data. |
| Share of bladder cancer incidence at specific cancer stage | Age at diagnosis: 1-year groups (ages 0 to 100)<br>Sex: males, females<br>Cancer stage: localized, regional, distant, unstaged | SEER 18 distribution of bladder cancer incidence over stages by age and sex at diagnosis | Distinct SEER 18 data were available for ages 0-44, 45-54, 55-64, 65-74, 75+. EPA assumed that the same cancer incidence shares by stage apply to all ages within each age group. |
| Share of cancer deaths among all-cause deaths | Age at diagnosis: 1-year groups (ages 0 to 100)<br>Sex: males, females<br>Cancer type: Kidney Cancer; Urinary Bladder (Invasive & In Situ) Cancer<br>Race/ethnicity: All, non-Hispanic White, non-Hispanic Black, Hispanic, non-Hispanic Other | Underlying Cause of Death, 1999-2019 on CDC WONDER Online Database (Centers for Disease Control and Prevention, 2020) | EPA calculated share of cancer deaths among all-cause deaths by race/ethnicity, age and sex by dividing the number of cancer deaths during 1999-2019 with the number of all-cause deaths during 1999-2019. |

**Table 4-5: Summary of Data Sources Used in Lifetime Health Risk Model**

| Data element | Modeled variability | Data source | Notes |
|---|---|---|---|
| Relative bladder cancer survival by cancer stage | Age at diagnosis: 1-year groups (ages 0 to 100)<br>Sex: males, females<br>Duration: 1-year groups (durations 0 to 100 years)<br>Cancer stage: localized, regional, distant, unstaged<br>Cancer type: Urinary Bladder (Invasive & In Situ) Cancer | SEER 18 relative bladder cancer survival by age at diagnosis, sex, cancer stage and duration with diagnosis for 2000-2017 (Surveillance Research Program - National Cancer Institute, 2020a) | Distinct SEER 18 data were available for ages at diagnosis 0-14, 15-39, 40-64, 65-74, 75+. EPA assumed that the same cancer relative survival patterns apply to all ages within each age group. SEER 18 contained data on relative survival among persons that had bladder cancer for 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, and 10 years. For disease durations longer than 10 years EPA applied 10-year relative survival rates. |

[a] EPA's Safe Drinking Water Information System SDWIS: https://www3.epa.gov/enviro/facts/sdwis/search.html

[b] ICF matched zip-code level populations from the 2019 ACS data (U.S. Census Bureau, 2019) to zip codes associated with each PWS in the SDWIS 2021 Q1 dataset (U.S. EPA, 2021c) or the UCMR 4 dataset (U.S. EPA, 2016a). The SDWIS dataset often contains a one-to-many relationship between PWS and zip codes served, whereas the UCMR 4 dataset provides a one-to-one relationship between PWS and zip codes.

[c] SEER program, National Cancer Institute, National Institute of Health

*Source: U.S. EPA Analysis, 2022.*

Table 4-6 summarizes sex- and age group-specific general population mortality rates and bladder cancer incidence rates used in the model simulations, as well as the sex-specific share of the affected population for each age group. *Appendix C* summarize sex- and age group-specific distribution of bladder cancer cases over four analyzed stages as well as the age of onset-specific relative survival probability for each stage.

Using available data on cancer incidence and mortality, EPA calculated changes in bladder cancer cases resulting from the regulatory options using the relationship between the change in TTHM concentrations and the change in lifetime bladder cancer risk estimated by Regli *et al.* (2015) (see Section 4.3.3.2). The analysis accounts for the gradual changes in lifetime exposures to TTHM following estimated changes in annual average bromide discharges and associated TTHM exposure under the regulatory options compared to the baseline.

**Table 4-6: Summary of Sex- and Age-specific Mortality and Bladder Cancer Incidence Rates**

| Sex | Age group | Sex-specific share of the affected population[a] | General population mortality rate (per 100,000)[b] | General population bladder cancer incidence rate (per 100,000)[b,c] |
|---|---|---|---|---|
| Female | <1 | 0.011 | 537 | 0.000 |
| Female | 1-4 | 0.044 | 36 | 0.000 |
| Female | 5-9 | 0.058 | 12 | 0.000 |
| Female | 10-14 | 0.060 | 10 | 0.000 |
| Female | 15-19 | 0.061 | 19 | 0.000 |
| Female | 20-24 | 0.063 | 40 | 0.009 |
| Female | 25-29 | 0.068 | 54 | 0.017 |
| Female | 30-34 | 0.070 | 73 | 0.034 |
| Female | 35-39 | 0.066 | 98 | 0.140 |
| Female | 40-44 | 0.063 | 135 | 0.310 |
| Female | 45-49 | 0.060 | 203 | 0.640 |
| Female | 50-54 | 0.063 | 317 | 1.300 |
| Female | 55-59 | 0.064 | 470 | 2.200 |
| Female | 60-64 | 0.064 | 675 | 4.000 |
| Female | 65-69 | 0.056 | 987 | 6.500 |
| Female | 70-74 | 0.048 | 1,533 | 12.000 |
| Female | 75-79 | 0.033 | 2,481 | 22.000 |
| Female | 80-84 | 0.022 | 4,171 | 36.000 |
| Female | 85+ | 0.025 | - | - |
| Male | <1 | 0.065 | 646 | 0.009 |
| Male | 1-4 | 0.065 | 44 | 0.000 |
| Male | 5-9 | 0.048 | 15 | 0.000 |
| Male | 10-14 | 0.012 | 12 | 0.009 |
| Male | 15-19 | 0.068 | 34 | 0.000 |
| Male | 20-24 | 0.073 | 112 | 0.012 |
| Male | 25-29 | 0.075 | 142 | 0.020 |
| Male | 30-34 | 0.069 | 159 | 0.046 |
| Male | 35-39 | 0.064 | 185 | 0.190 |
| Male | 40-44 | 0.060 | 229 | 0.520 |
| Male | 45-49 | 0.063 | 323 | 1.400 |
| Male | 50-54 | 0.063 | 508 | 3.100 |
| Male | 55-59 | 0.063 | 784 | 7.100 |
| Male | 60-64 | 0.061 | 1136 | 12.000 |
| Male | 65-69 | 0.051 | 1593 | 22.000 |

**Table 4-6: Summary of Sex- and Age-specific Mortality and Bladder Cancer Incidence Rates**

| Sex | Age group | Sex-specific share of the affected population[a] | General population mortality rate (per 100,000)[b] | General population bladder cancer incidence rate (per 100,000)[b,c] |
|---|---|---|---|---|
| Male | 70-74 | 0.042 | 2304 | 37.000 |
| Male | 75-79 | 0.027 | 3577 | 70.000 |
| Male | 80-84 | 0.017 | 5770 | 123.000 |
| Male | 85+ | 0.015 | - | - |

[a] Shares calculated for the total population served by potentially affected PWS, based on county-level data.

[b] Based on the general population of the United States.

[c] Single age-specific rates were aggregated up to the age groups reported in the table using the individual age-specific number of affected persons as weights.

*Source: U.S. EPA analysis (2022) of 2019 ACS data (U.S. Census Bureau, 2019).*

#### *4.3.3.4 Model Implementation*

EPA analyzed effects of the regulatory options using the dynamic microsimulation model and data sources described in Section 4.3.3.3. As described above, EPA models TTHM changes (ΔTTHM) due to the regulatory options as being in effect for the years 2025 through 2049. After 2049, EPA does not attribute costs or changes in bromide loadings to the rule, and therefore does not model incremental changes in exposures to TTHM.[56]

To estimate changes in bladder cancer incidence, EPA defined and quantified a set of 110,898 unique combinations[57] of the following parameters:

- *Location and TTHM changes*: 549 PWS groups;[58]
- *Age*: age of the population at the start of the evaluation period (2025), ranging from 0 to 100;
- *Sex*: population sex (male or female).

### *4.3.4 Quantifying the Monetary Value of Benefits*

EPA estimated total monetized benefits from avoided morbidity and mortality (also referred to as avoided cancer cases and avoided cancer deaths, respectively, in this discussion) from estimated changes in bromide discharges, and estimated changes in TTHM exposure and the resulting estimated bladder cancer incidence rate using 3 percent and 7 percent discount rates for each of the four regulatory options.[59]

- *Morbidity*: To value changes in the economic burden associated with cancer morbidity EPA used estimates of annual medical expenses for bladder cancer treatment from Greco *et al.* (2019) and the

56 In other words, costs after 2049 = $0 and Δbromide after 2049 is zero (hence ΔTTHM after 2049 is zero).

57 The set of 110,898 combinations was determined by multiplying the number of PWS groups by the number of ages and sexes considered (549 x 101 x 2).

58 The PWS groups represent unique combinations of location (county) and ΔTTHM values and typically consist of a directly affected PWS and other PWSs serving populations located in the same county and purchasing water from the directly affected PWS. The number of PWS in each PWS group ranges from 1 to 11.

59 In some cases, benefits are derived from a delay in cancer morbidity and mortality.

estimated life years with cancer morbidity (differentiating between first and subsequent years after cancer diagnosis). For invasive cancer, the medical treatment costs are $50,061 and $3,420 per case for the first and subsequent years respectively. For non-invasive cancer, medical treatment costs are $18,272 and $1,270 per case for the first and subsequent years, respectively.

- *Mortality*: To value changes in excess mortality from bladder cancer EPA extrapolated the default central tendency of the VSL distribution recommended for use in EPA's regulatory impact analyses, $4.8 million (1990 USD, 1990 income year), to future years, ranging from $11.69 million per death in 2021 to $14.01 million per death in 2049 (U.S. EPA, 2010b). The product of VSL and the estimated aggregate reduction in risk of death in a given year represents the affected population's aggregate WTP to reduce its probability of death in one year.

## 4.4 Results of Analysis of Human Health Benefits from Estimated Changes in Bromide Discharges Analysis

Using the data EPA assembled on cancer incidence and mortality, the Agency estimated changes in bladder cancer cases for the regulatory options using the relationship between TTHM concentrations and the lifetime bladder cancer risk estimated by Regli *et al.* (2015). Figure 4-3 and Figure 4-4 show the estimated number of bladder cancer cases and premature deaths avoided, respectively, under the four regulatory options by decade. In each decade, the estimated number of bladder cancer cases is never in excess of 35 cases and the estimated number of premature deaths avoided is never in excess of nine deaths avoided.

Consistent with the relatively small decrease in bromide loadings for Option 1 in Table 3-1, this option would result in a relatively small decrease in cancer incidence and mortality as compared to the baseline. Options 2, 3, and 4 generally show larger decreases in cancer incidence and mortality over the period of analysis. More than 50 percent of the modeled avoided bladder cancer incidence associated with Options 1, 2, 3, and 4 occurs between 2025 and 2054. This pattern is consistent with existing cancer cessation lag models (*e.g.*, Hrubec & McLaughlin, 1997, Hartge *et al.*, 1987, and Chen & Gibb, 2003) that show between 61 and 94 percent reduction in cancer risk in the first 25 years after exposure cessation (see *Appendix C* for detail). After 2054, the benefits attributable to exposures incurred under the regulatory options in 2025-2049 decline due to comparably fewer people surviving to mature ages.[60] In the years after 2085, the avoided cases decline considerably and in the last decade considered in the analysis, the cancer incidences increase relative to baseline incidences.[61]

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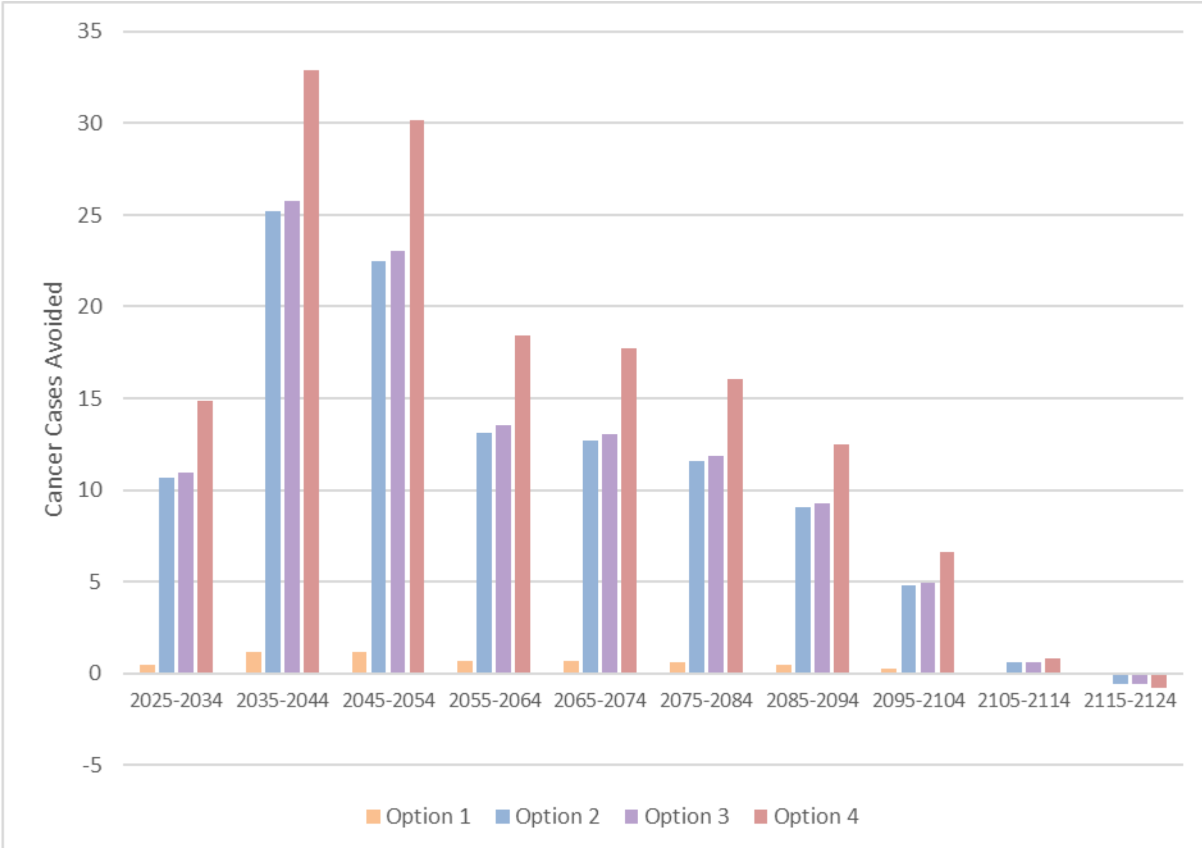
[60] In the period between 2055 and 2084, the estimated avoided cases decline slowly as the living people exposed to the estimated changes in TTHM levels reach 70 years (the age at which the highest annual incidence of bladder cancer is observed). According to American Cancer Society, about 9 out of 10 people diagnosed with bladder cancer are over the age of 55. The average age at the time of diagnosis is 73 (U.S. Census Bureau, 2019).

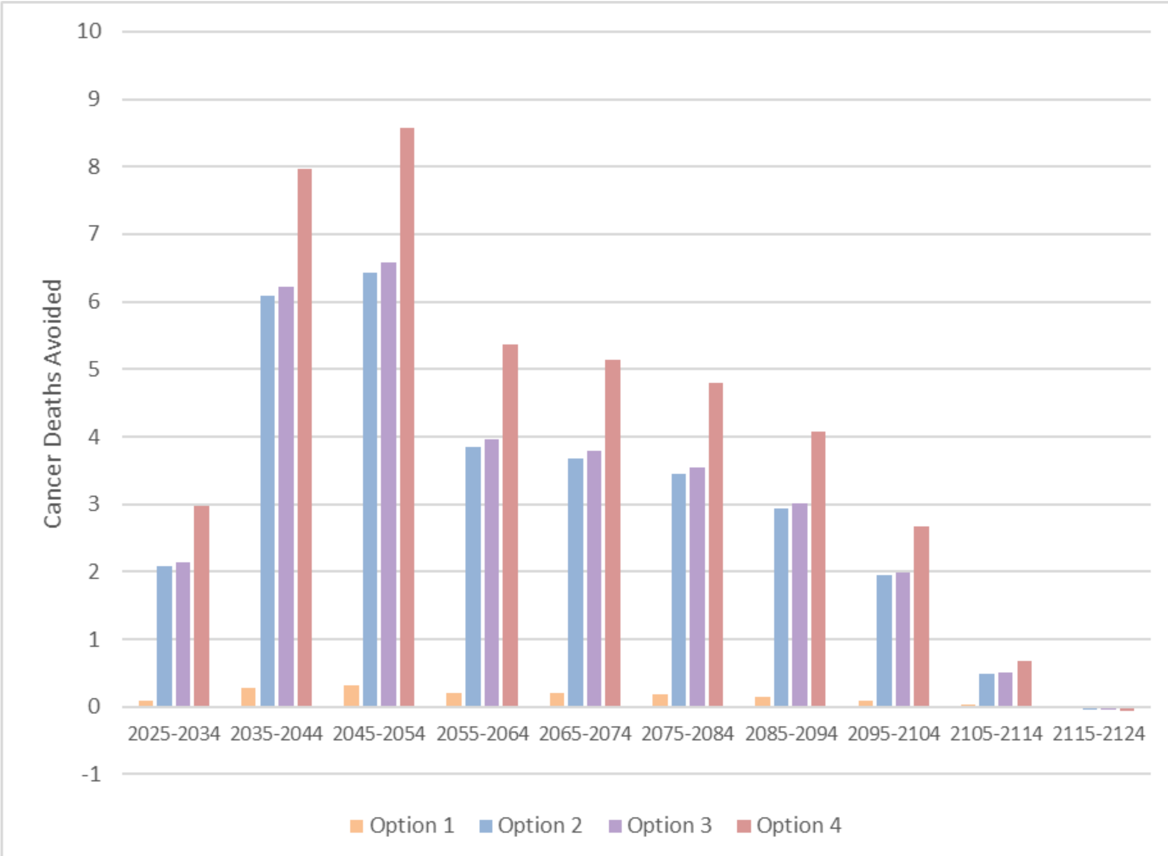
[61] The increase in cancer cases in the last decade is due to the connection between survival and cancer incidence. Lower estimated TTHM exposure due to reductions in bromide loadings under certain regulatory options reduces the estimated number of people developing bladder cancer during the earlier years of the analysis and increases overall survival rates. Higher estimated rates of survival lead to longer life spans and more people developing cancer later in life. This effect becomes more apparent closer to the end of the evaluation period, at which point there are fewer people estimated to be alive in the baseline population compared to the estimated number of people alive under certain regulatory option scenarios.

**Figure 4-3: Estimated Number of Bladder Cancer Cases Avoided under the Regulatory Options.**




*Source: U.S. EPA Analysis, 2022.*

**Figure 4-4: Estimated Number of Cancer Deaths Avoided under the Regulatory Options.**




*Source: U.S. EPA Analysis, 2022.*

Table 4-7 summarizes the estimated changes in the incidence of bladder cancer from exposure to TTHM due to the regulatory options and the value of benefits from avoided cancer cases, including avoided mortality and morbidity.

**Table 4-7: Estimated Bromide-related Bladder Cancer Mortality and Morbidity Monetized Benefits**

| Regulatory Option | Changes in cancer cases from changes in TTHM exposure 2025-2049[a] | | Benefits (million 2021$, discounted to 2024) | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Total bladder cancer cases avoided | Total cancer deaths avoided | Annualized[b] benefits from avoided mortality | | Annualized[b] benefits from avoided morbidity | | Total annualized[b] benefits | |
| | | | 3% | 7% | 3% | 7% | 3% | 7% |
| 1 | 5 | 2 | $0.45 | $0.13 | $0.00 | $0.00 | $0.45 | $0.28 |
| 2 | 110 | 31 | $9.29 | $6.04 | $0.08 | $0.05 | $9.37 | $6.09 |
| 3 | 112 | 32 | $9.53 | $6.19 | $0.08 | $0.05 | $9.61 | $6.24 |
| 4 | 149 | 42 | $12.60 | $8.19 | $0.10 | $0.07 | $12.70 | $8.26 |

[a] The analysis accounts for the persisting health effects (up until 2125) from changes in TTHM exposure during the period of analysis (2025-2049).

[b] Benefits are annualized over 25 years.

*Source: U.S. EPA Analysis, 2022*

These estimated total benefits are not uniformly distributed across plants that discharge bromide. For example, out of the 86 steam electric power plants included in this analysis, under Option 2 more than 85 percent of total benefits are attributable to discharge changes at only seven steam electric power plants. Similarly, approximately 85 percent of the benefits of Option 3 come from seven steam electric power plants and approximately 85 percent of the benefits of Option 4 come from changes at nine steam electric power plants. Figure 4-5 illustrates the plant-level contributions to total annualized benefits for Options 2, 3, and 4 during Period 2. Only a single plant contributes to total annualized benefits for Option 1, so it is not shown in Figure 4-5.

**Figure 4-5: Contributions of Individual Steam Electric Power Plants to Total Annualized Benefits of Changes in Bromide Discharges under the Regulatory Options (3 Percent Discount Rate)**

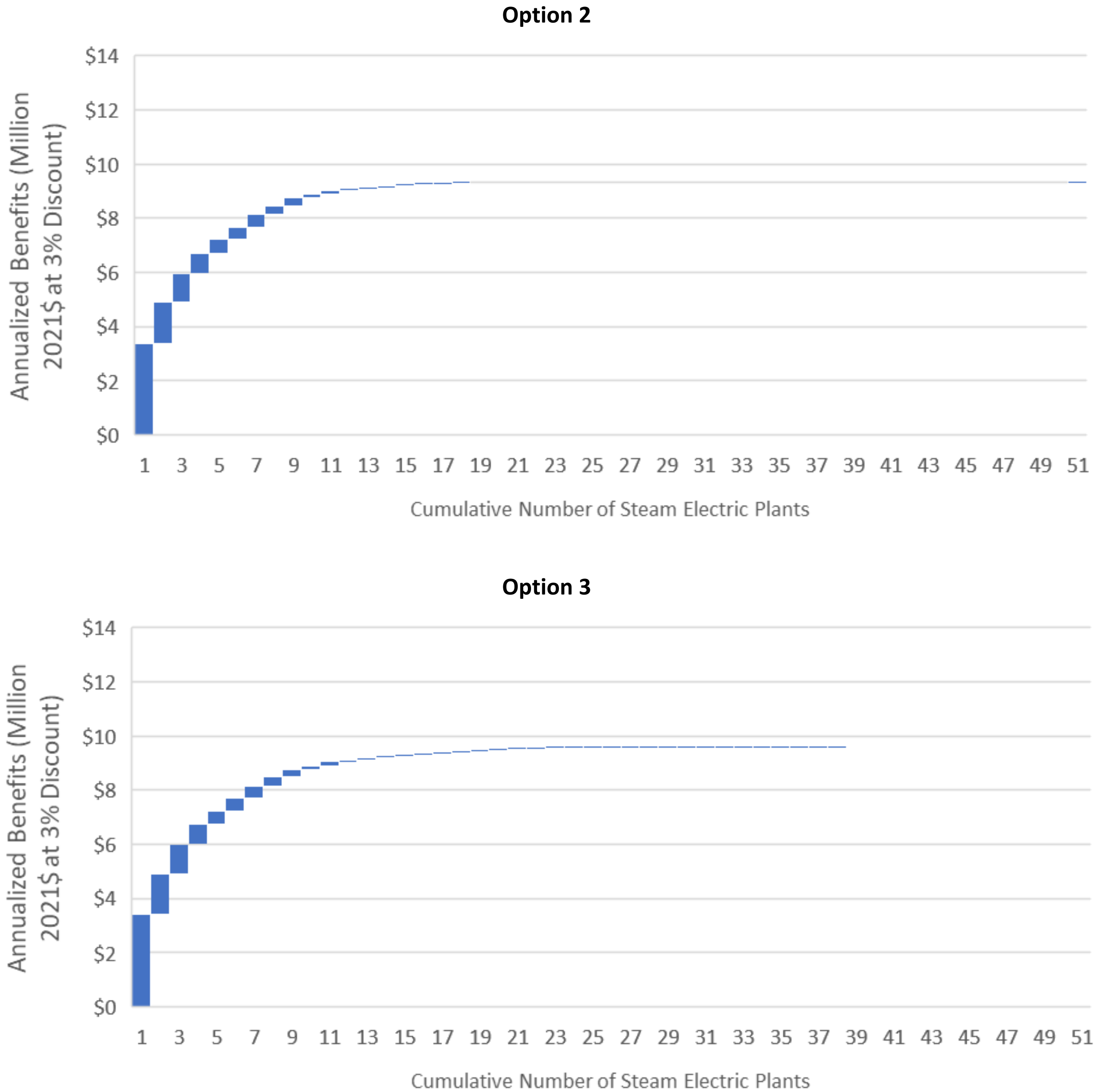
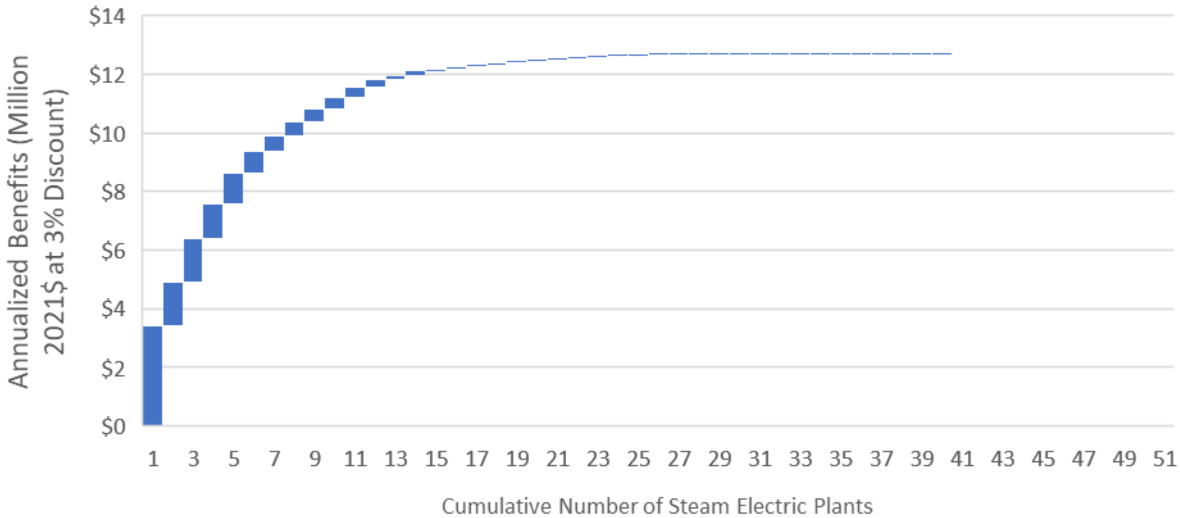


**Figure 4-5: Contributions of Individual Steam Electric Power Plants to Total Annualized Benefits of Changes in Bromide Discharges under the Regulatory Options (3 Percent Discount Rate)**

**Option 4**




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

The regulatory options may result in relatively 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. In addition to certain brominated DBPs discussed in the previous sections, there are no "safe levels" for lead and arsenic and therefore any reduction in exposure to these pollutants is expected to yield benefits.[62]

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 small (*e.g.*, less than 0.02 µg/L in Period 1 and less than 0.004 µg/L in Period 2 in source waters). Table 4-8 summarizes the direction of changes in arsenic, lead, and thallium concentrations under the regulatory options for the two analysis periods. The magnitude 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 3-1). During Period 1, all Options show either reductions or no changes in arsenic, lead, and thallium concentrations for all source waters and PWS. During Period 2, the four

[62] Even in cases where the MCLG is equal to the MCL, there may be incremental health-related benefits associated with changes in concentrations arising from the regulatory options since detection of the pollutants is subject to imperfect monitoring and treatment may not remove all contaminants from the drinking water supplies, as evidenced by reported MCL violations for inorganic and other contaminants at community water systems (U.S. EPA, 2013b).

Options also show estimated reductions in arsenic, lead, and thallium concentrations with both the magnitude and scope (the number of reaches, PWS, and population served) of the reductions 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 exceeding MCLs or MCLGs. EPA did this analysis for all of the pollutants listed in Table 2-2, except bromate and TTHM.[63] 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 4-8.[64] 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 relatively small.

**Table 4-8: 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 (Millions) | |
|---|---|---|---|---|---|---|
| | Reduction | No Change | Reduction | No Change | Reduction | No Change |
| **Period 1 (2025-2029)** | | | | | | |
| **Arsenic** | | | | | | |
| Option 1 | 117 | 102 | 378 | 497 | 15.0 | 25.9 |
| Option 2 | 144 | 75 | 534 | 341 | 15.9 | 25.0 |
| Option 3 | 171 | 48 | 677 | 198 | 30.6 | 10.4 |
| Option 4 | 172 | 47 | 679 | 196 | 30.6 | 10.3 |
| **Lead** | | | | | | |
| Option 1 | 4 | 166 | 11 | 626 | 0.4 | 31.9 |
| Option 2 | 86 | 84 | 311 | 326 | 7.2 | 25.2 |
| Option 3 | 140 | 30 | 565 | 72 | 25.2 | 7.1 |
| Option 4 | 157 | 13 | 608 | 29 | 27.0 | 5.3 |
| **Thallium** | | | | | | |
| Option 1 | 4 | 215 | 11 | 864 | 0.4 | 40.5 |
| Option 2 | 86 | 133 | 311 | 564 | 7.2 | 33.8 |
| Option 3 | 140 | 79 | 565 | 310 | 25.2 | 15.7 |
| Option 4 | 157 | 62 | 608 | 267 | 27.0 | 13.9 |
| **Period 2 (2030-2049)** | | | | | | |
| **Arsenic** | | | | | | |
| Option 1 | 166 | 53 | 585 | 290 | 25.4 | 15.5 |
| Option 2 | 192 | 27 | 737 | 138 | 26.3 | 14.6 |
| Option 3 | 218 | 1 | 873 | 2 | 40.8 | 0.1 |
| Option 4 | 219 | 0 | 875 | 0 | 40.9 | 0.0 |
| **Lead** | | | | | | |
| Option 1 | 4 | 166 | 11 | 626 | 0.4 | 31.9 |
| Option 2 | 92 | 78 | 328 | 309 | 7.4 | 24.9 |

63 EPA did not consider MCL or MCLG exceedances for bromate and TTHM because the background data on these contaminants in source waters is not readily available (*e.g.*, these contaminants are not included in the TRI dataset). Additionally, modeled discharges of bromate from steam electric plant effluent do not exceed EPA's MCL of 0.01 mg/L, but all exceed the MCLG of zero.

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

**Table 4-8: 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 (Millions) | |
|---|---|---|---|---|---|---|
| | Reduction | No Change | Reduction | No Change | Reduction | No Change |
| Option 3 | 153 | 17 | 594 | 43 | 30.4 | 1.9 |
| Option 4 | 170 | 0 | 637 | 0 | 32.3 | 0.0 |
| **Thallium** | | | | | | |
| Option 1 | 4 | 215 | 11 | 864 | 0.4 | 40.5 |
| Option 2 | 92 | 127 | 328 | 547 | 7.4 | 33.5 |
| Option 3 | 153 | 66 | 594 | 281 | 30.4 | 10.5 |
| Option 4 | 170 | 49 | 637 | 238 | 32.3 | 8.6 |

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

*Source: U.S. EPA Analysis, 2022.*

## 4.6 Limitations and Uncertainties

Table 4-9 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, 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 4-9: 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 |
|---|---|---|
| Analysis does not account for births within the exposed population. | Underestimate | The analysis does not account for people born after 2025. This likely leads to an underestimate of benefits. |
| Analysis does not account for migration within the exposed population. | Uncertain | The analysis does not account for people leaving or moving into the service area. The overall effect of this factor on the estimated benefits is uncertain. |
| Bladder cancer risks are estimated for populations for which changes in TTHM exposures relative to baseline exposures start at different ages, including children. | Uncertain | The relative cancer potency of TTHM in children is unknown, which may bias benefits estimates either upward or downward. Past reviews found no clear evidence that children are at greater risk of adverse effects from bromoform or dibromochloromethane exposure (U.S. EPA, 2005a) although certain modes of action and health effects may be associated with exposure to TTHM during childhood (U.S. EPA, 2016c). Because bladder cancer incidence in children is very small, EPA assesses any bias to be negligible. |
| 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. |

**Table 4-9: 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 |
|---|---|---|
| Changes in bromide 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. |
| Changes in TTHM formation depends only on changes in bromide levels. | Uncertain | The regulatory options are expected to affect bromide levels in source water. Other factors such as disinfection method, pH, temperature, and organic content affect TTHM formation. EPA assumes that PWS and source waters affected by steam electric power plant discharges have similar characteristics as those modeled in Regli *et al.* (2015). |
| Use of a national relationship from Regli *et al.* (2015) to relate changes in bromide concentration to changes in TTHM concentration. | Uncertain | EPA did not collect site-specific information on factors affecting TTHM formation at each potentially affected drinking water treatment plant, but instead used the median from a sample population of approximately 200 drinking water treatment systems. Use of the national relationship from Regli *et al.* (2015) could either understate or overstate actual changes in TTHM concentrations for a given change in bromide concentrations at any specific drinking water treatment system. |
| Change in risk is based on changes in exposure to TTHMs rather than to brominated trihalomethanes specifically. | Underestimate | Brominated species play a prominent role in the overall toxicity of DBP exposure. Given that the regulatory options predominantly affect the formation of brominated DBPs, the estimated changes in cancer risk resulting from regulatory options could be biased downward. EPA report provides additional information about health effects of DBPs (U.S. EPA, 2016c). |
| The analysis relies on public-access SEER 18 5-year relative bladder cancer survival data to model mortality patterns in the bladder cancer population. | Uncertain | Reliance on these data generates both a downward and an upward bias. The downward bias is due to the short, 5-year excess mortality follow-up window. Survival rates beyond 5 years following the initial diagnosis are likely to be lower. The upward bias comes from the inability to determine how many of the excess deaths were deaths from bladder cancer. |
| The dose-response function used to estimate risk assumes causality of bladder cancer from exposure to disinfected drinking water. | Overestimate | While the evidence supporting causality has increased since EPA’s Stage 2 DBP Rule, the weight of evidence is still not definitive (see Regli *et al.* (2015)). |

**Table 4-9: 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 |
|---|---|---|
| The relationship from Regli *et al.* (2015) is a linear approximation of the odds ratios reported in Villanueva *et al.* (2004). | Uncertain | Given the uncertainty about the historical, location-specific TTHM baselines, Regli et al. (2015) provides a reasonable approximation of the risk. However, depending on the baseline TTHM exposure level, the impact computed based on Regli *et al.* (2015) may be larger or smaller than the impact computed using the Villanueva *et al.* (2004) -reported odds ratios directly. |
| The analysis does not account for the relationship between TTHM exposure and bladder cancer within certain subpopulations. | Overestimate | Epidemiological literature suggests that TTHM effects could be greatest for the smoker population, whose members are already at higher risk for bladder cancer. Smoking prevalence has declined in the United States and relationships estimated with data from the 1980s and 1990s may overestimate future bladder cancer impact. Robust synthesis estimates of the relationship between TTHM and bladder cancer in the smoker population are lacking, limiting EPA's ability to account for smoking when modeling health effects. |
| The change in risk for a given change in TTHM is uncertain for changes in TTHM concentrations that are less than 1 µg/L. | Uncertain | EPA notes that the majority of the regulatory options benefits are associated with PWS for which predicted changes in TTHM concentration are greater than 1 µg/L. Although there is greater uncertainty in the estimated changes in health risk associated with changes in TTHM concentrations less than 1 µg/L, EPA included these changes in the estimated benefits. Benefits from the regulatory options may be greater or smaller than estimated, depending on actual risk changes. EPA |
| Health effects associated with DBP exposure other than bladder cancer are not quantified in this analysis. | Uncertain | An EPA report discusses potential linkages between DBP exposures and other health endpoints, *e.g.*, developmental effects (with a short-term exposure) and cancers other than bladder cancers (with a long-term exposure), but there is insufficient data to fully evaluate these endpoints (U.S. EPA, 2016c). |
| 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. |
| 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. |

**Table 4-9: 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 |
|---|---|---|
| The analysis does not account for populations that consume bottled water as their primary drinking water source or populations that practice averting behaviors such as purchasing bottled water and filters in response to drinking water violations. | Uncertain | Studies indicate that between 13% and 33% of the U.S. population consumes bottled water as their primary drinking water source (Hu *et al.*, 2011; Rosinger *et al.*, 2018; Vieux *et al.*, 2020). Recent research also documents a relationship between sales of bottled water and violations of the SDWA (Allaire *et al.*, 2019). The benefits models do not consider populations who consume bottled water as their primary drinking water source or populations that practice averting behaviors in response to poor drinking water quality. The overall effect of not considering these populations on the estimated benefits is uncertain. |

# 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 EA (U.S. EPA, 2023a) provides details on the health effects of steam electric pollutants. Recreational and subsistence fishers (and their household members) who consume fish caught[65] 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, FGD wastewater and CRL 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[66] 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 EA (U.S. EPA, 2023a). 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,[67] 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

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65 As detailed in Sections 5.2 and 5.8, for the subset of recreational and subsistence fishers who consume catch from affected reaches (*i.e.*, do not practice catch-and-release), EPA assumed that all fish consumed consists of self-caught fish. EPA assumed no exposure via fish consumption for all other households, including recreational and subsistence fishers who consume catch from other reaches.

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

67 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.

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.

## 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.[68] 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).[69] 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 2019 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:[70] 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.[71] 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.[72] 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.[73] After subdividing population groups by age, race, fishing mode, and poverty indicator, each CBG has 196 unique

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68 The in-scope population excludes recreational and subsistence fishers who fish other reaches or certain affected waterbodies not covered by the water quality models (*i.e.*, Great Lakes and estuaries).

69 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.

70 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.

71 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.

72 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).

73 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.

population cohorts (7 age groups × 7 ethnic/racial groups × 2 fishing modes [recreational versus subsistence fishing] × 2 poverty status designations).

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 EJA document for details of the EJ analysis. As noted below, distinguishing the exposed population in this manner 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.** $$\boldsymbol{ExPop}(\boldsymbol{i})(\boldsymbol{s})(\mathbf{c}) = \boldsymbol{Pop}(\boldsymbol{i})(\mathbf{c}) \times \%\boldsymbol{Fish}(\boldsymbol{s}) \times \boldsymbol{CaR}(\boldsymbol{c})$$

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 2019 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.[74] 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 2019 population data and not adjusted for population growth during the analysis period). Of the total population, 16 percent live within 50 miles of an affected reach and participate in recreational and/or subsistence fishing, and 12 percent are potentially exposed to fish contaminated by steam electric pollutants in bottom ash transport water, FGD wastewater, and CRL discharges.

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74 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 2019)** | |
|---|---|
| Total population | 121,117,555 |
| Total fishers population[a] | 19,063,667 |
| Population potentially exposed to contaminated fish[b, c] | 14,843,924 |

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 2025 through 2049 is 12.1 percent higher than the population in 2019 presented in the table, or 16.6 million people. The analysis estimates that the fraction of the U.S. population engaged in recreational and subsistence fishing remains constant from 2025 through 2049.

*Source: U.S. EPA Analysis, 2022*

## 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,[75] 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 E in U.S. EPA (2020b 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. See *Appendix 0* for additional details about the derivation of fish tissue concentration values.

75 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 EA (U.S. EPA, 2023a) 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 EA for details (U.S. EPA, 2023a).

*Source: U.S. EPA Analysis, 2022*

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 (2023a).

**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%)

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

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

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,[76] and motor skill deficits (see NTP, 2012; U.S. EPA, 2013d, 2019d, 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, 2019d). 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, 2019d; 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 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, 2021a), 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

[76] 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).

seven one-year age cohorts from birth through the seventh birthday. Based on the estimated 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[77] 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 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:

$\beta_1$ = -3.315 (log-linear regression coefficient on the lifetime blood lead level[78])

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 2019 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 represent an annual value (*i.e.*, it would apply to the

77 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.

78 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).

cohort of children born each year after implementation).[79] Equation 5-6 shows this calculation for the annual increase in total IQ points.

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

Where:

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

*Ln(ΔGM(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, 2019c). 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 0*).

**Table 5-3: Value of an IQ Point (2021$) based on Expected Reductions in Lifetime Earnings**

| Discount Rate | Value of an IQ Point[a,b] (2021$) |
|---|---|
| 3 percent | $22,381 |
| 7 percent | $4,875 |

a. Values are adjusted for the cost of education.

b. EPA adjusted the value of an IQ point to 2021 dollars using the GDP deflator.

*Source: U.S. EPA, 2019c 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

[79] 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.

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 for compensatory education are negligible and are not included in the total monetized benefits.

### *5.3.2 Results*

Table 5-4 shows the benefits associated with changes in IQ losses from lead exposure via consumption of self-caught fish. Avoided IQ point losses over the entire in-scope population of children with changes in lead exposure ranges from 1 point (Option 1) to 6 points (Options 3 and 4). Estimated annualized benefits from avoided IQ losses are $0.01 million for Options 3 and 4 using a 3 percent discount rate. Otherwise, the estimated annualized benefits are less than $0.01 million.

**Table 5-4: Estimated Benefits from Avoided 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 Avoided IQ Point Losses, 2025 to 2049 in All Children 0 to 7 in Scope of the Analysis[c] | Annualized Value of Avoided IQ Point Losses[a] (Millions 2021$) | |
|---|---|---|---|---|
| | | | 3% Discount Rate | 7% Discount Rate |
| Option 1 | 1,427,107 | 1 | <$0.01 | <$0.01 |
| Option 2 | 1,427,107 | 2 | <$0.01 | <$0.01 |
| Option 3 | 1,427,107 | 6 | $0.01 | <$0.01 |
| Option 4 | 1,427,107 | 6 | $0.01 | <$0.01 |

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 (2019c).

b. 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.

c. 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.

*Source: U.S. EPA Analysis, 2022*

## 5.4 Heath Effects in Children from Changes in Mercury Exposure

Mercury can have a variety of adverse health effects on adults and children (U.S. EPA, 2023a). 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 outcomes. 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. Therefore, this analysis only reflects health effects from consumption of self-caught fish by households. Also, 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.[80] 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 2019 in the National Vital Statistics Report (Martin *et al.*, 2021). 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 65.3, followed by African Americans at 64.4, other race/ethnicities at 58.3, Native Americans at 56.2, and Caucasians and Asians at 55.3.

### *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. As EPA is not aware of consumption rates specific to pregnant women, the analysis uses the same consumption rates as in the general population within each analyzed cohort.

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.

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)(c)* = 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

80 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.

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, 2019e). The IQ values discounted to birth range from $3,980 to $20,482. EPA also used an alternative value of an IQ point from Lin *et al.* (2018) in a sensitivity analysis (see *Appendix 0*.

### *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. Avoided IQ point losses over the entire in-scope population of infants with changes in mercury exposure ranges from 3,712 points (Option 1) to 3,923 points (Option 4). Using a 3 percent discount rate, the annualized benefits of avoided IQ point losses range from $2.94 million (Option 1) to $3.11 million (Options 3 and 4). Using a 7 percent discount rate, estimates range from $0.54 million (Option 1) to $0.58 million (Options 3 and 4).

**Table 5-5: Estimated Benefits from Avoided 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[b] | Total Avoided IQ Point Losses, 2025 to 2049 in All Infants in Scope of the Analysis | Annualized Value of Avoided IQ Point Losses[a] (Millions 2021$) | |
|---|---|---|---|---|
| | | | 3% Discount Rate | 7% Discount Rate |
| Option 1 | 187,496 | 3,712 | $2.94 | $0.54 |
| Option 2 | 187,496 | 3,776 | $2.99 | $0.55 |
| Option 3 | 187,496 | 3,920 | $3.11 | $0.58 |
| Option 4 | 187,496 | 3,923 | $3.11 | $0.58 |

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 (2019e).

b. 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.

*Source: U.S. EPA Analysis, 2022*

## 5.5 Estimated Changes in Cancer Cases from Arsenic Exposure

Among steam electric pollutants that can contaminate fish tissue and are analyzed in the EA, arsenic is the only confirmed carcinogen with a published dose response function (see U.S. EPA, 2010b).[81] 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 negligible changes in skin cancer cases from exposure to arsenic via

81 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.

consumption of self-caught fish under the regulatory options.[82] Accordingly, the estimated benefits are also negligible under all regulatory options and are not included in the total monetized benefits.

## 5.6 Monetary Values of Estimated Changes in Human Health Effects

Table 5-6 presents the estimated benefits under the regulatory options of changes in adverse human health outcomes associated with the consumption of self-caught fish. Using a 3 percent discount rate, the estimated benefits range from $2.94 million (Option 1) to $3.12 million (Option 4). Using a 7 percent discount rate, the estimated benefits range from $0.54 million (Option 1) to $0.58 million (Options 3 and 4). Changes in mercury exposure for children account for the majority of total monetary values from increases in adverse health outcomes.

**Table 5-6: Estimated Benefits of Changes in Human Health Outcomes Associated with Fish Consumption under the Regulatory Options, Compared to Baseline (Millions of 2021$)**

| Discount Rate | Regulatory Option | Changes in Lead Exposure for Children[a,b,c] | Changes in Mercury Exposure for Children[a,b] | Total[a,b] |
|---|---|---|---|---|
| 3% | Option 1 | $0.00 | $2.94 | $2.94 |
| | Option 2 | $0.00 | $2.99 | $2.99 |
| | Option 3 | $0.00 | $3.11 | $3.11 |
| | Option 4 | $0.01 | $3.11 | $3.12 |
| 7% | Option 1 | $0.00 | $0.54 | $0.54 |
| | Option 2 | $0.00 | $0.55 | $0.55 |
| | Option 3 | $0.00 | $0.58 | $0.58 |
| | Option 4 | $0.00 | $0.58 | $0.58 |

## 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.[83] 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.

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[82] The analysis estimated a reduction in the incidence of arsenic-related skin cancer cases of 0.01 cases between 2025 and 2049 for all four regulatory options.

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

Table 5-7 shows the results of this analysis.[84] 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 350 reaches based on the "consumption of water and organism" criteria, and 51 reaches based on the "consumption of organism only" criteria nationwide. During Period 2, concentrations of steam electric pollutants exceed human health criteria for at least one pollutant in 346 reaches based on the "consumption of water and organism" criteria, and 51 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 and with exceedances of "consumption of organism only" criteria during both Period 1 and Period 2 decreases under all regulatory options.[85] For example, Option 3 eliminates exceedances in 286 reaches (346-60) and reduces the number of exceedances in 301 reaches.

**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 Lower Number of Exceedances, Relative to Baseline[b] | |
|---|---|---|---|---|
| | Consumption of Water + Organism | Consumption of Organism Only | Consumption of Water + Organism | Consumption of Organism Only |
| **Period 1 (2025-2029)** | | | | |
| Baseline | 350 | 51 | Not applicable | Not applicable |
| Option 1 | 268 | 44 | 90 | 15 |
| Option 2 | 267 | 44 | 91 | 15 |
| Option 3 | 255 | 44 | 103 | 15 |
| Option 4 | 255 | 44 | 103 | 15 |
| **Period 2 (2030-2049)** | | | | |
| Baseline | 346 | 51 | Not applicable | Not applicable |
| Option 1 | 84 | 19 | 272 | 42 |
| Option 2 | 84 | 17 | 277 | 47 |
| Option 3 | 60 | 14 | 301 | 47 |
| Option 4 | 60 | 14 | 301 | 47 |

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

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

*Source: U.S. EPA Analysis, 2022*

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

[85] EPA's analysis does not account for 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. Additional limitations and uncertainties associated with the environmental assessment analyses and data are discussed in the EA (see U.S. EPA, 2023a).

**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, 2013c) |
| Fish intake rates used in estimating exposure do not reflect potential lower fish consumption by pregnant women. | Overestimate | To the degree that pregnant women reduce their consumption of self-caught fish when compared to women in the general population, then exposure in the baseline would be less and the proposed rule benefits from reduced exposure to mercury correspondingly lower. |

**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 |
|---|---|---|
| 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, 2013c). |
| 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 overall number of potentially affected subsistence fishers (and their households) and ignores potential variability in subsistence fishing rates across racial/ethnic groups and different geographic locations. |
| Value of an IQ point used to quantify benefits health effects from changes in lead and mercury exposure | Uncertain | EPA used two alternative estimates of the value of an IQ point in its analysis, following the methodology in U.S. EPA (2019c; 2019d, 2020b). EPA acknowledges recent research indicating higher IQ point values than those calculated based on Salkever (1995) and Lin *et al.* (2018). However, because the recent research was based on either non-U.S. populations (*e.g.*, Grönqvist *et al.*, 2020 ) or unrepresentative subsets of the U.S. population (Hollingsworth *et al.*, 2020; Hollingsworth & Rudik, 2021),EPA continued to use IQ point values based on Salkever (1995) and Lin *et al.* (2018). |
| 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; U.S. EPA, 2005c). 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). |

**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 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.*, Navas-Acien, 2021; 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, 2013d; U.S. EPA, 2019d). 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. |
| 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. While there are no existing methods to fully analyze and monetize these effects, EPA quantified some of these effects in the EA (U.S. EPA, 2023a). |

# 6 Nonmarket Benefits from Water Quality Changes

As discussed in the EA (U.S. EPA, 2023a), 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) 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 and 2020 rules (U.S. EPA, 2015a, 2020b). 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 improvements 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 in U.S. EPA (2020b) describes EPA's approach.

## 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 189 estimates of total WTP (including both use and nonuse values) for water quality improvements, provided by 59 original studies conducted between 1981 and 2017.[86] 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 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:

86 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 Smith *et al.* (2002, p. 134) , "nearly all benefit cost analyses rely on benefit transfers, whether they acknowledge it or not."

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 main estimate of non-market benefits, and Model 2 is used in a sensitivity analysis to develop a range of estimates that account for uncertainty in the estimated WTP values (see Section 6.2 for Model 2 results). *Appendix H* 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 names and definitions of the independent variable 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-3) by the variable levels calculated for each CBG or fixed at the levels indicated in the "Assigned Value" column in Table G-3. The sum of these products represents the predicted natural log of the WTP for a one-point improvement on the WQI (*ln_OWTP*) for a representative household in each CBG. Equation 6-1 provides the equation used to calculate household benefits for each CBG.

**Equation 6-1.**

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

where:

| | | |
|---|---|---|
| $HWTP_{Y,B}$ | = | Annual household WTP in 2021$ in year *Y* for households located in the CBG (*B*), |
| $OWTP_{Y,B}$ | = | WTP for a one-point improvement on the WQI 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, |
| $\Delta WQI_B$ | = | Estimated annual average water quality change for the CBG (*B*). |

To estimate WTP for water quality improvements under the regulatory options, EPA first estimated water quality improvements 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 improvements are estimated for all years from 2025 through 2049. As summarized in Table 6-1, average annual household WTP estimates for the regulatory options, based on the main estimates from Model 1, range from $0.05 under Options 1 and 2 to $0.06 under Options 3 and 4.

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 CBG in a given year and calculated the present value (PV) of the stream of WTP over the 25 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.**

$$TWTP_B = \left( \sum_{T=2025}^{2049} \frac{HWTP_{Y,B} \times HH_{Y,B}}{(1+i)^{Y-2024}} \right) \times \left( \frac{i \times (1+i)^n}{(1+i)^{n+1} - 1} \right)$$

where:

| | | |
|---|---|---|
| $TWTP_B$ | = | Annualized total household WTP in 2021$ for households located in the CBG (*B*), |
| $HWTP_{Y,B}$ | = | Annual household WTP in 2021$ 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 (25 years)[87] |

EPA generated annual household counts for each CBG through the period of analysis based on projected population growth following the method described in Section 1.3.6. Table 6-1 presents the main analysis results, based on Model 1 and using 3 percent and 7 percent discount rates. The total annualized values of water quality changes resulting from changes in toxics, nutrient and sediment discharges in these reaches range from $2.6 million under Option 1 (7 percent discount rate) to $4.3 million under Option 4 (3 percent discount rate).

**Table 6-1: Estimated Household and Total Annualized Willingness-to-Pay for Water Quality Improvements under the Regulatory Options, Compared to Baseline (Main Estimates)**

| Regulatory Option | Number of Affected Households (Millions)[a] | Average Annual WTP Per Household (2021$)[b] | Total Annualized WTP (Millions 2021$)[b] | |
|---|---|---|---|---|
| | | | 3% Discount Rate | 7% Discount Rate |
| Option 1 | 76.2 | $0.05 | $3.02 | $2.64 |
| Option 2 | 80.6 | $0.05 | $3.82 | $3.32 |
| Option 3 | 82.1 | $0.06 | $4.09 | $3.56 |
| Option 4 | 82.1 | $0.06 | $4.27 | $3.73 |

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

b. Estimates based on Model 1, which provides EPA's main estimate of non-market benefits.

*Source: U.S. EPA Analysis, 2022*

## 6.2 Sensitivity Analysis

Table 6-2 presents sensitivity analysis results produced from Model 2, including average annual household WTP and total annualized values, for water quality improvements resulting from all regulatory options. Average annual household WTP estimates for the regulatory options range from $0.05 under Option 1 (low estimate) to $0.13 under Options 2, 3, and 4 (high estimate). Total annualized values range from $3.0 million under Option 1 (low estimate, 7 percent discount rate) to $9.9 million under Option 4 (high estimate, 3 percent discount rate). The main estimates presented in Table 6-1 are closer to the low end of the sensitivity analysis range.

87 See Section 1.3.3 for details on the period of analysis.

**Table 6-2: Estimated Household and Total Annualized Willingness-to-Pay for Water Quality Changes under the Regulatory Options, Compared to Baseline (Sensitivity Analysis)**

| Regulatory Option | Number of Affected Households (Millions)[a] | Average Annual WTP Per Household (2021$)[b] | | Total Annualized WTP (Millions 2021$)[b] | | | |
|---|---|---|---|---|---|---|---|
| | | | | 3% Discount Rate[a,b] | | 7% Discount Rate[a] | |
| | | Low | High | Low | High | Low | High |
| Option 1 | 76.2 | $0.05 | $0.11 | $3.50 | $7.17 | $3.00 | $6.14 |
| Option 2 | 80.6 | $0.06 | $0.13 | $4.35 | $8.92 | $3.72 | $7.63 |
| Option 3 | 82.1 | $0.06 | $0.13 | $4.64 | $9.50 | $3.97 | $8.13 |
| Option 4 | 82.1 | $0.07 | $0.13 | $4.83 | $9.88 | $4.14 | $8.48 |

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

b. Estimates based on Model 2, which provides a range of estimates that account for uncertainty in the WTP estimates as a sensitivity analysis. For the ΔWQI variable setting in Model 2-based sensitivity analysis, EPA used values of 20 units to develop low estimates and 7 units to develop high estimates (see *Appendix 0* for details).

*Source: U.S. EPA Analysis, 2022*

## 6.3 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.

Separate from this rule, EPA and the Department of the Army recently announced plans to refine methods used to estimate wetlands benefits. The plans include peer review of how meta-analyses are applied to estimate benefits from wetlands preservation and developing a standardized approach that increases the reliability and transparency of the estimation methods. Specifically, the agencies stated:

> "Outside of this rulemaking, the agencies plan to further refine aspects of their approach to valuing benefits associated with preserving wetlands, including incorporating ecosystem service effects. The agencies plan to undertake peer review on aspects of their approach including examination of influential variables and the agencies' application of the meta-analysis." (U.S. Environmental Protection Agency and Department of the Army, 2022)

EPA's benefits valuation for CWA regulations to date has not considered the combined effects on rivers, streams, lakes reservoirs, wetlands, and other relevant water bodies, including interactions among quality in these waters. Outside of this rulemaking, it is EPA's intention to explore such methodologies so more integrated analyses of ecosystem services may be possible in the future, and EPA will follow its standards for appropriate peer review of such future methodological updates on valuing water quality, including surface water quality.

| **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 MRM. 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 *lnquality_ch* variable value in Model 2 for estimating a range of WTP values (sensitivity analysis) | Uncertain | The value of an additional one-point improvement in WQI is expected to decline as the magnitude of the water quality change increases. To account for variability in WTP due to the magnitude of the valued water quality changes, EPA estimated a range of WTP values for a one-point improvement on the WQI using alternative settings for *lnquality_ch* (ΔWQI= 20 and 7 units, respectively). These values were based on the 25$^{th}$ and 75$^{th}$ percentile of water quality changes included in the meta-data. To ensure that the benefit transfer function satisfies the adding-up condition, this variable is treated as a methodological (fixed) variable. The negative coefficient for *lnquality_ch* implies that larger value settings produce smaller WTP estimates for a one-point improvement, which is consistent with economic theory; smaller value settings produce larger WTP estimates for a one-point improvement. The selected values may bias the estimated WTP values either upward or downward. |
| 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 presentation of water quality changes 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. To account for potential effects of the use of a different water quality metric (*i.e.*, index of biotic integrity (IBI)) on WTP values for a one-point improvement on the WQI, EPA used a dummy variable in the MRM (see *Appendix 0* for details). In benefit transfer applications, the IBI variable is set to zero, which is consistent with using the WQI. |

**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. Although meta-analyses are often more accurate compared to other types of transfer approaches due to the data synthesis from multiple source studies (Rosenberger and Phipps, 2007; Johnston *et al.*, 2021), there is still a potential for transfer errors (Shrestha *et al.*, 2007) and no transfer method is always superior (Johnston *et al.*, 2021). |
| Omission of Great Lakes and estuaries from analysis of benefits from water quality changes | Underestimate | Five out of 92 (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 EA (U.S. EPA, 2023a), 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.[88].

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.

88 Criteria are developed based on the 1985 Guidelines methods (U.S. EPA, 1985) and generally reflect high quality toxicity data from at least eight 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 for the analyses of the 2015 and 2020 rules (U.S. EPA, 2015a, 2020b), including updates EPA made to the methodology, assumptions, and inputs as part of the 2020 rule analysis.

## 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 may be 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 proposed 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 199 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 0* 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 | 20 | 5 | 1 | 26 |
| Clams | 0 | 0 | 63 | 63 |
| Crustaceans | 0 | 2 | 3 | 5 |
| Fishes | 0 | 0 | 35 | 35 |
| Insects | 10 | 0 | 0 | 10 |
| Mammals | 15 | 1 | 1 | 16 |
| Reptiles | 15 | 1 | 3 | 19 |
| Snails | 2 | 0 | 9 | 11 |
| **Total** | **70** | **11** | **118** | **199** |

*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 proposed rule (see *Appendix 0* 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 (2025-2029 and 2030-2049) within the overall analysis period (2025-2049). 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 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[89] 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's analysis indicates that thirty-six reaches intersecting habitat ranges of twenty-eight T&E species exceed NRWQC under the baseline conditions in Period 1 and thirty-four reaches intersecting habitat ranges of twenty-three T&E species exceed NRWQC under the baseline conditions in Period 2. In Period 1 (2025-2029), no baseline exceedances are eliminated under Options 1 and 2, whereas under Options 3 and 4 exceedances are eliminated in three reaches, potentially benefitting five T&E fish species (Canada lynx (T), Colorado pikeminnow (E), Razorback sucker (E), Southwestern willow flycatcher (E), and Yellow-billed cuckoo (T)). In Period 2 (2030-2049), NRWQC exceedances are eliminated or reduced in five reaches, potentially benefitting three species (Northern Long-Eared Bat (T), Piping Plover (E), and Topeka Shiner (E)). Table 7-2 provides additional detail on the number of exceedances potentially affecting T&E species vulnerable to discharges from steam electric power plants.

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89 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).

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

| Species Name | State | Number of Reaches with NRWQC Exceedances for at Least One Pollutant | | | | |
|---|---|---|---|---|---|---|
| | | Baseline | Option 1 | Option 2 | Option 3 | Option 4 |
| **Period 1 (2025-2029)** | | | | | | |
| Clubshell | Kentucky | 1 | 1 | 1 | 1 | 1 |
| Colorado pikeminnow | New Mexico | 2 | 2 | 2 | 0 | 0 |
| Fanshell | Kentucky/West Virginina | 18 | 18 | 18 | 18 | 18 |
| Orangefoot pimpleback (pearlymussel) | Kentucky | 1 | 1 | 1 | 1 | 1 |
| Pink mucket (pearlymussel) | Kentucky/Ohio/West Virginia | 19 | 19 | 19 | 19 | 19 |
| Razorback sucker | New Mexico | 2 | 2 | 2 | 0 | 0 |
| Ring pink (mussel) | Kentucky | 1 | 1 | 1 | 1 | 1 |
| Rough pigtoe | Kentucky | 1 | 1 | 1 | 1 | 1 |
| Sheepnose Mussel | West Virginia/Ohio | 18 | 18 | 18 | 18 | 18 |
| Snuffbox mussel | West Virginia | 17 | 17 | 17 | 17 | 17 |
| Spectaclecase (mussel) | West Virginia | 17 | 17 | 17 | 17 | 17 |
| Topeka shiner | Kansas | 7 | 7 | 7 | 7 | 7 |
| West Indian Manatee | Florida | 5 | 5 | 5 | 5 | 5 |
| **Period 2 (2030-2049)** | | | | | | |
| Clubshell | Kentucky | 1 | 1 | 1 | 1 | 1 |
| Fanshell | Kentucky/West Virginina | 18 | 18 | 18 | 18 | 18 |
| Orangefoot pimpleback (pearlymussel) | Kentucky | 1 | 1 | 1 | 1 | 1 |
| Pink mucket (pearlymussel) | Kentucky/Ohio/West Virginia | 19 | 19 | 19 | 19 | 19 |
| Ring pink (mussel) | Kentucky | 1 | 1 | 1 | 1 | 1 |
| Rough pigtoe | Kentucky | 1 | 1 | 1 | 1 | 1 |
| Sheepnose Mussel | West Virginia/Ohio | 18 | 18 | 18 | 18 | 18 |
| Snuffbox mussel | West Virginia | 17 | 17 | 17 | 17 | 17 |
| Spectaclecase (mussel) | West Virginia | 17 | 17 | 17 | 17 | 17 |
| Topeka shiner | Kansas | 7 | 7 | 2 | 2 | 2 |
| West Indian Manatee | Florida | 5 | 5 | 5 | 5 | 5 |

*Source: U.S. EPA Analysis, 2022*

## 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) (L. 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 (Subroy *et al.*, 2019; L. Richardson & Loomis, 2009). In addition, use of the MRMs developed by Subroy *et al.* (2019) and L. Richardson and Loomis (2009) is not feasible for this analysis due to the challenges associated with estimating T&E population changes from the proposed rule. Table 7-3 summarizes limitations and uncertainties known to affect EPA's assessment of the impacts of the proposed 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 7-3: 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 7-3: 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 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. Additionally, the water quality model does not capture synergistic relationships between pollutants, which may exacerbate adverse effects on T&E species. |

# 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 increases in wastewater treatment costs compared to the baseline and the resulting changes in EGU relative operating costs.

EPA estimated the climate-related benefits of changes in $CO_2$ emissions, as well as the human health benefits resulting from changes in particulate matter and ozone ambient exposure due to 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.

## 8.1 Changes in Air Emissions

With respect to the third mechanism mentioned in the introduction and as discussed in the RIA, EPA used the Integrated Planning Model (IPM) to estimate the electricity market-level effects of the proposed rule (Option 3; see Chapter 5 in RIA [U.S. EPA, 2023c]). IPM projects generation from coal to decrease in all model years as a result of the proposed rule. Over the period of analysis, the reductions are smallest in 2028 (1.2 thousand GWh) and highest in 2045 (11.5 thousand GWh). These changes are offset in part by an increase in generation from natural gas, nuclear, and renewables. See details in Chapter 5 of the RIA (U.S. EPA, 2023c). The net effects of these changes in the generation mix are reductions in air emissions that reflect differences in EGU emissions rates for these other fuels or sources of energy, as compared to coal.

IPM outputs include estimated $CO_2$, $NO_X$, and $SO_2$ emissions to air from EGUs.[90] EPA also used IPM outputs to estimate EGU emissions of primary $PM_{2.5}$ based on emission factors described in U.S. EPA (2020c). Specifically, EPA estimated primary $PM_{2.5}$ 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 3 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 proposed rule.[91] EPA used six of the seven IPM run years, shown in Table 8-1, to represent the period of analysis. IPM provides outputs starting in 2028 and EPA therefore estimated no changes in air emissions from changes in electricity generation in 2025 through 2027. The last run year (2055) falls outside of the analysis period of 2025-2049 and EPA does not include results for that year when estimating benefits.

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90 EPA also estimated Hg, HCl and $PM_{10}$ emissions but does not use these estimates for the benefits analysis.

91 While EPA only ran IPM for the proposed rule (Option 3), the Agency extrapolated the benefits estimated using these IPM outputs to options 1, 2, and 4 to provide insight on the potential air quality-related effects of the other regulatory options. See Section 8.4 for details.

**Table 8-1: IPM Run Years**

| IPM Run Year | Years Represented |
|---|---|
| 2028 | 2028 |
| 2030 | 2029-2031 |
| 2035 | 2032-2037 |
| 2040 | 2038-2042 |
| 2045 | 2043-2047 |
| 2050 | 2048-2052 |
| 2055 | 2053-2059 |

*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 and ash handling systems, and changes in transportation needed to landfill solid waste and CCR (see TDD for details; U.S. EPA, 2023d). 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 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 and Table 8-3 respectively summarize the estimated changes in emissions associated with changes in power requirements to operate treatment systems and with the incremental transportation of CCR and solid waste under the regulatory options. For consistency, the tables present estimates for selected IPM model years. EPA modeled emissions in each year based on when each plant is estimated to implement technologies for each wastestream and any announced unit retirements. EPA estimates that changes in power requirements and transportation will increase emissions slightly, relative to the baseline. The variations across regulatory options reflect differences in treatment technologies and affected steam electric plants, whereas variations across model years for a given regulatory option reflect the timing of technology implementation and announced EGU retirements.[92]

**Table 8-2: Estimated Changes in Air Pollutant Emissions Due to Increase in Power Requirements at Steam Electric Power Plants 2025-2049, Compared to Baseline**

| 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 1** | | | | |
| 2028 | 0.016 | 0.012 | 0.013 | Not estimated |
| 2030 | 0.030 | 0.020 | 0.022 | Not estimated |
| 2035 | 0.030 | 0.020 | 0.022 | Not estimated |
| 2040 | 0.030 | 0.020 | 0.022 | Not estimated |
| 2045 | 0.030 | 0.020 | 0.022 | Not estimated |
| 2050 | 0.030 | 0.020 | 0.022 | Not estimated |

92 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 2025 through 2029, as well as announced EGU retirements during the period of analysis. For EGUs that retire during the analysis period, incremental power requirements and trucking associated with BA transport water and FGD wastewater treatment cease, but those associated with CRL continue even after the unit retires.

**Table 8-2: Estimated Changes in Air Pollutant Emissions Due to Increase in Power Requirements at Steam Electric Power Plants 2025-2049, Compared to Baseline**

| 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 2** | | | | |
| 2028 | 0.074 | 0.040 | 0.038 | Not estimated |
| 2030 | 0.12 | 0.064 | 0.060 | Not estimated |
| 2035 | 0.12 | 0.064 | 0.060 | Not estimated |
| 2040 | 0.12 | 0.064 | 0.060 | Not estimated |
| 2045 | 0.12 | 0.064 | 0.058 | Not estimated |
| 2050 | 0.12 | 0.064 | 0.058 | Not estimated |
| **Option 3 (Proposed Rule)** | | | | |
| 2028 | 0.083 | 0.046 | 0.048 | Not estimated |
| 2030 | 0.13 | 0.072 | 0.071 | Not estimated |
| 2035 | 0.13 | 0.072 | 0.070 | Not estimated |
| 2040 | 0.13 | 0.072 | 0.070 | Not estimated |
| 2045 | 0.13 | 0.071 | 0.067 | Not estimated |
| 2050 | 0.13 | 0.071 | 0.067 | Not estimated |
| **Option 4** | | | | |
| 2028 | 0.087 | 0.050 | 0.050 | Not estimated |
| 2030 | 0.14 | 0.078 | 0.075 | Not estimated |
| 2035 | 0.14 | 0.074 | 0.072 | Not estimated |
| 2040 | 0.13 | 0.073 | 0.072 | Not estimated |
| 2045 | 0.13 | 0.073 | 0.069 | Not estimated |
| 2050 | 0.13 | 0.073 | 0.069 | Not estimated |

a. Values rounded to two significant figures. Positive values indicate an increase in emissions.

*Source: U.S. EPA Analysis, 2022*

**Table 8-3: Estimated Changes in Air Pollutant Emissions Due to Increase in Trucking at Steam Electric Power Plants 2025-2049, Compared to Baseline**

| 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 1** | | | | |
| 2028 | 0.000035 | 0.00010 | 0.00000012 | Not estimated |
| 2030 | 0.000090 | 0.00025 | 0.00000031 | Not estimated |
| 2035 | 0.000090 | 0.00025 | 0.00000031 | Not estimated |
| 2040 | 0.000090 | 0.00025 | 0.00000031 | Not estimated |
| 2045 | 0.000090 | 0.00025 | 0.00000031 | Not estimated |
| 2050 | 0.000090 | 0.00025 | 0.00000031 | Not estimated |
| **Option 2** | | | | |
| 2028 | 0.00012 | 0.00032 | 0.00000039 | Not estimated |
| 2030 | 0.00023 | 0.00065 | 0.00000079 | Not estimated |
| 2035 | 0.00023 | 0.00065 | 0.00000079 | Not estimated |
| 2040 | 0.00023 | 0.00065 | 0.00000079 | Not estimated |
| 2045 | 0.00023 | 0.00065 | 0.00000079 | Not estimated |
| 2050 | 0.00023 | 0.00065 | 0.00000079 | Not estimated |

**Table 8-3: Estimated Changes in Air Pollutant Emissions Due to Increase in Trucking at Steam Electric Power Plants 2025-2049, Compared to Baseline**

| 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 3 (Proposed Rule)** | | | | |
| 2028 | 0.0030 | 0.0067 | 0.000010 | Not estimated |
| 2030 | 0.0044 | 0.0099 | 0.000015 | Not estimated |
| 2035 | 0.0040 | 0.0091 | 0.000014 | Not estimated |
| 2040 | 0.0039 | 0.0088 | 0.000013 | Not estimated |
| 2045 | 0.0037 | 0.0085 | 0.000013 | Not estimated |
| 2050 | 0.0037 | 0.0085 | 0.000013 | Not estimated |
| **Option 4** | | | | |
| 2028 | 0.0035 | 0.0080 | 0.000012 | Not estimated |
| 2030 | 0.0054 | 0.012 | 0.000018 | Not estimated |
| 2035 | 0.0048 | 0.011 | 0.000017 | Not estimated |
| 2040 | 0.0046 | 0.011 | 0.000016 | Not estimated |
| 2045 | 0.0045 | 0.010 | 0.000015 | Not estimated |
| 2050 | 0.0045 | 0.010 | 0.000015 | Not estimated |

a. Values rounded to two significant figures. Positive values indicate an increase in emissions.

*Source: U.S. EPA Analysis, 2022*

Table 8-4 summarizes the estimated changes in pollutant emissions from electricity generation under the proposed rule (*i.e.*, Option 3).[93] Projected changes in the profile of electricity generation under Option 3, compared to the baseline, generally lead to national-level reductions in emissions for all air pollutants modeled. The largest decline occurs in model year 2045, followed by 2035 (2050 for $SO_2$). At the national level, $CO_2$ emissions decrease by 0.8 to 12 million tons, depending on the year, which is 0.1 to 1.1 percent of corresponding baseline emissions. $NO_x$ emissions decrease by 1.9 to 7.6 thousand tons (0.6 to 2.4 percent); $SO_2$ emissions decrease by 1.0 to 9.3 thousand tons (0.2 to 3.9 percent); and primary $PM_{2.5}$ decrease by 0.12 to 0.75 thousand tons (0.1 to 1.2 percent). The impact on emissions varies across regions and by pollutant with emissions increasing in some and decreasing in other NERC regions, as detailed in the RIA (Table 5-4; U.S. EPA, 2023c).

**Table 8-4: 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 3 (Proposed Rule) | 2028 | -0.83 | -1.9 | -1.0 | -0.12 |
| | 2030 | -4.8 | -3.4 | -2.0 | -0.20 |
| | 2035 | -11 | -5.2 | -5.9 | -0.32 |
| | 2040 | -7.3 | -3.8 | -4.5 | -0.19 |
| | 2045 | -12 | -7.6 | -9.3 | -0.75 |
| | 2050 | -3.1 | -2.1 | -7.6 | -0.13 |

a. Values rounded to two significant figures. Negative values indicate a reduction in emissions.

*Source: U.S. EPA Analysis, 2022; See Chapter 5 in RIA for details on IPM (U.S. EPA, 2023c).*

93 EPA did not run IPM for Options 1, 2, and 4.

A comparison of estimated changes in emissions across the three mechanisms (Table 8-2, Table 8-3 and Table 8-4) for the proposed rule (Option 3) shows that the largest effect on projected air emissions comes from the change in the emissions profile of electricity generation at the market level. Table 8-5 presents the net changes in emissions of the four pollutants compared to baseline. The next two sections quantify the climate change and human health benefits associated with changes in emissions under the proposed rule (Option 3).

**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 3 (Proposed Rule) | 2028 | -0.75 | -1.9 | -1.0 | -0.12 |
| | 2030 | -4.7 | -3.3 | -2.0 | -0.20 |
| | 2035 | -11 | -5.1 | -5.8 | -0.32 |
| | 2040 | -7.2 | -3.7 | -4.4 | -0.19 |
| | 2045 | -12 | -7.5 | -9.3 | -0.75 |
| | 2050 | -3.0 | -2.0 | -7.6 | -0.13 |

a. Values rounded to two significant figures. Negative values indicate a net reduction in emissions.

*Source: U.S. EPA Analysis, 2022*

## 8.2 Climate Change Benefits

### *8.2.1 Data and Methodology*

EPA estimated the climate benefits of the net $CO_2$ emission changes expected from this proposed rule using the estimates of the social cost of greenhouse gases (SC-GHG)[94], specifically using the social cost of carbon (SC-$CO_2$). The SC-$CO_2$ is the monetary value of the net harm to society associated with a marginal increase in $CO_2$ emissions in a given year, or the benefit of avoiding that increase. In principle, the SC-$CO_2$ includes the value of all climate change impacts (both negative and positive), including (but not limited to) changes in net agricultural productivity, human health effects, property damage from increased flood risk and natural disasters, disruption of energy systems, risk of conflict, environmental migration, and the value of ecosystem services. The SC-$CO_2$ therefore reflects the societal value of reducing emissions of the gas in question by one metric ton and is the theoretically appropriate value to use in conducting benefit-cost analyses of policies that affect $CO_2$ emissions. In practice, data and modeling limitations naturally restrain the ability of SC- $CO_2$ estimates to include all the important physical, ecological, and economic impacts of climate change, such that the estimates are a partial accounting of climate change impacts and will therefore, tend to be underestimates of the marginal benefits of abatement. The EPA and other Federal agencies began regularly incorporating SC-$CO_2$ estimates in their benefit-cost analyses conducted under Executive Order (EO) 12866[95] since 2008,

94 Estimates of the social cost of greenhouse gases are gas specific (*e.g.*, social cost of carbon (SC-$CO_2$), social cost of methane (SC-$CH_4$), social cost of nitrous oxide (SC-$N_2O$)), but collectively they are referenced as the social cost of greenhouse gases (SC-GHG).

95 Presidents since the 1970s have issued executive orders requiring agencies to conduct analysis of the economic consequences of regulations as part of the rulemaking development process. EO 12866, released in 1993 and still in effect today, requires that for all economically significant regulatory actions, an agency provide an assessment of the potential costs and benefits of the regulatory action, and that this assessment include a quantification of benefits and costs to the extent feasible. For purposes of this action, monetized climate benefits are presented for purposes of providing a complete benefit-cost analysis under EO 12866

following a Ninth Circuit Court of Appeals remand of a rule for failing to monetize the benefits of reducing $CO_2$ emissions in that rulemaking process.

In 2017, the National Academies of Sciences, Engineering, and Medicine published a report that provides a roadmap for how to update SC-GHG estimates used in Federal analyses going forward to ensure that they reflect advances in the scientific literature (National Academies, 2017). The National Academies' report recommended specific criteria for future SC-GHG updates, 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. The research community has made considerable progress in developing new data and methods that help to advance various components of the SC-GHG estimation process in response to the National Academies' recommendations.

In a first-day executive order (EO 13990), Protecting Public Health and the Environment and Restoring Science to Tackle the Climate Crisis, President Biden called for a renewed focus on updating estimates of the social cost of greenhouse gases (SC-GHG) to reflect the latest science, noting that "it is essential that agencies capture the full benefits of reducing greenhouse gas emissions as accurately as possible." Important steps have been taken to begin to fulfill this directive of EO 13990. In February 2021, the IWG released a technical support document (hereinafter the "February 2021 TSD") that provided a set of IWG recommended SC-GHG estimates while work on a more comprehensive update is underway to reflect recent scientific advances relevant to SC-GHG estimation (IWG, 2021). In addition, as discussed further below, EPA has developed a draft updated SC-GHG methodology within a sensitivity analysis in the regulatory impact analysis of EPA's November 2022 supplemental proposal for oil and gas standards that is currently undergoing external peer review and a public comment process.[96]

The EPA has applied the IWG's recommended interim SC-GHG estimates in the Agency's regulatory benefit-cost analyses published since the release of the February 2021 TSD and is likewise using them in this BCA. EPA evaluated the SC-GHG estimates in the February 2021 TSD and determined that these estimates are appropriate for use in estimating the social benefits of GHG reductions expected to occur as a result of the final rule and alternative standards. These SC-GHG estimates are interim values developed for use in benefit-cost analyses until updated estimates of the impacts of climate change can be developed based on the best available science and economics. After considering the TSD, and the issues and studies discussed therein, EPA concludes that these estimates, while likely an underestimate, are the best currently available SC-$CO_2$ estimates until revised estimates have been developed reflecting the latest, peer-reviewed science.

The SC-$CO_2$ estimates presented in the February 2021 SC-GHG TSD were developed over many years, using transparent process, peer-reviewed methodologies, the best science available at the time of that process, and with input from the public. Specifically, in 2009, an IWG that included EPA and other executive branch agencies and offices was established to ensure that agencies had access to the best available information when quantifying the benefits of reducing $CO_2$ emissions in benefit-cost analyses. The IWG published SC-$CO_2$ estimates in 2010 that were developed from an ensemble of three widely cited integrated assessment models (IAMs) that estimate climate damages using highly aggregated representations of climate processes and the global economy combined into a single modeling framework. The three IAMs were run using a common set

and other relevant executive orders. The estimates of change in GHG emissions and the monetized benefits associated with those changes play no part in the record basis for this action.

96 See https://www.epa.gov/environmental-economics/scghg

of input assumptions in each model for future population, economic, and $CO_2$ emissions growth, as well as equilibrium climate sensitivity (ECS) — a measure of the globally averaged temperature response to increased atmospheric $CO_2$ concentrations. These estimates were updated in 2013 based on new versions of each IAM.[97] In August 2016 the IWG published estimates of the social cost of methane (SC-$CH_4$) and nitrous oxide (SC-$N_2O$) using methodologies that are consistent with the methodology underlying the SC-$CO_2$ estimates. In 2015, as part of the response to public comments received to a 2013 solicitation for comments on the SC-$CO_2$ estimates, the IWG announced a National Academies of Sciences, Engineering, and Medicine review of the SC-$CO_2$ estimates to offer advice on how to approach future updates to ensure that the estimates continue to reflect the best available science and methodologies. In January 2017, the National Academies released their final report, *Valuing Climate Damages: Updating Estimation of the Social Cost of Carbon Dioxide*, 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, 2017). Shortly thereafter, in March 2017, President Trump issued EO 13783, which disbanded the IWG, withdrew the previous technical support documents, and directed agencies to "ensure" SC-GHG estimates used in regulatory analyses "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)). Benefit-cost analyses following EO 13783, including the benefit-cost analysis for the 2020 Steam Electric Reconsideration Rule (U.S. EPA, 2020b), used SC-GHG estimates that attempted to focus on the specific share of climate change damages in the U.S. as captured by the models (which did not reflect many pathways by which climate impacts affect the welfare of U.S. citizens and residents) and were calculated using two default discount rates recommended by Circular A-4 (OMB, 2003), 3 percent and 7 percent.[98] All other methodological decisions and model versions used in the SC-GHG calculations remained the same as those used by the IWG in 2010 and 2013, respectively.

On January 20, 2021, President Biden issued EO 13990, which re-established an IWG and directed the group to develop an update of the SC-GHG estimates that reflect the best available science and the recommendations of National Academies (2017). In February 2021, the IWG recommended the interim use of the most recent SC-GHG estimates developed by the IWG prior to the group being disbanded in 2017, adjusted for inflation (IWG, 2021). As discussed in the February 2021 SC-GHG TSD, the IWG's selection of these interim estimates reflected the immediate need to have SC-GHG estimates available for agencies to use in regulatory benefit-cost analyses and other applications that were developed using a transparent process, peer reviewed methodologies, and the science available at the time of that process. The February 2021 update also recognized the limitations of the interim estimates and encouraged agencies to use their best judgment in, for example, considering sensitivity analyses using lower discount rates. The IWG published a Federal Register notice on May 7, 2021, soliciting comment on the February 2021 SC-GHG TSD and on how best to

97 Dynamic Integrated Climate and Economy (DICE) 2010 (Nordhaus, 2010), Climate Framework for Uncertainty, Negotiation, and Distribution (FUND) 3.8 (Anthoff & Tol, 2013a, 2013b), and Policy Analysis of the Greenhouse Gas Effect (PAGE) 2009 (Hope, 2012).

98 EPA regulatory analyses under EO 13783 included sensitivity analyses based on global SC-GHG values and using a lower discount rate of 2.5 percent. OMB Circular A-4 (OMB, 2003) recognizes that special considerations arise when applying discount rates if intergenerational effects are important. In the IWG's 2015 *Response to Comments*, OMB—as a co-chair of the IWG—made clear that "Circular A-4 is a living document," that "the use of 7 percent is not considered appropriate for intergenerational discounting," and that "[t]here is wide support for this view in the academic literature, and it is recognized in Circular A-4 itself." OMB, as part of the IWG, similarly repeatedly confirmed that "a focus on global SCC estimates in [regulatory impact analyses] is appropriate" (IWG, 2015).

incorporate the latest peer-reviewed scientific literature in order to develop an updated set of SC-GHG estimates. The EPA has applied the IWG's interim SC-GHG estimates in regulatory analyses published since the release of the February 2021 SC-GHG TSD, and is likewise using them in the benefit-cost analysis calculations in this BCA.

As noted above, EPA participated in the IWG but has also independently evaluated the interim SC-$CO_2$ estimates published in the February 2021 TSD and determined they are appropriate to use to estimate climate benefits for this action. EPA and other agencies intend to undertake a fuller update of the SC- $CO_2$ estimates that takes into consideration the advice of the National Academies (2017) and other recent scientific literature. EPA has also evaluated the supporting rationale of the February 2021 TSD, including the studies and methodological issues discussed therein, and concludes that it agrees with the rationale for these estimates presented in the TSD and summarized below. The February 2021 SC-GHG TSD provides a complete discussion of the IWG's initial review conducted under EO 13990. In particular, the IWG found that the SC-GHG estimates used under EO 13783 fail to reflect the full impact of GHG emissions in multiple ways. First, the IWG concluded that those estimates fail to capture many climate impacts that can affect the welfare of U.S. citizens and residents. Examples of affected interests include direct effects on U.S. citizens and assets located abroad, international trade, and tourism, and spillover pathways such as economic and political destabilization and global migration that can lead to adverse impacts on U.S. national security, public health, and humanitarian concerns. Those impacts are better captured within global measures of the social cost of greenhouse gases.

In addition, assessing the benefits of U.S. GHG mitigation activities requires consideration of how those actions may affect mitigation activities by other countries, as those international mitigation actions will provide a benefit to U.S. citizens and residents by mitigating climate impacts that affect U.S. citizens and residents. A wide range of scientific and economic experts have emphasized the issue of reciprocity as support for considering global damages of GHG emissions. Using a global estimate of damages in U.S. analyses of regulatory actions allows the U.S. to continue to actively encourage other nations, including emerging major economies, to take significant steps to reduce emissions. The only way to achieve an efficient allocation of resources for emissions reduction on a global basis — and so benefit the U.S. and its citizens — is for all countries to base their policies on global estimates of damages.

As a member of the IWG involved in the development of the February 2021 SC-GHG TSD, EPA agrees with this assessment and, therefore, in this BCA EPA centers attention on a global measure of SC-$CO_2$. This approach is the same as that taken in EPA regulatory analyses over 2009 through 2016. A robust estimate of climate damages only to U.S. citizens and residents that accounts for the myriad of ways that global climate change reduces the net welfare of U.S. populations does not currently exist in the literature. As explained in the February 2021 TSD, existing estimates are both incomplete and an underestimate of total damages that accrue to the citizens and residents of the U.S. because they do not fully capture the regional interactions and spillovers discussed above, nor do they include all of the important physical, ecological, and economic impacts of climate change recognized in the climate change literature, as discussed further below. The EPA, as a member of the IWG, will continue to review developments in the literature, including more robust methodologies for estimating the magnitude of the various damages to U.S. populations from climate impacts and reciprocal international mitigation activities, and explore ways to better inform the public of the full range of carbon impacts.

Second, the IWG concluded that the use of the social rate of return on capital (7 percent under current OMB Circular A-4 guidance) to discount the future benefits of reducing GHG emissions inappropriately underestimates the impacts of climate change for the purposes of estimating the SC-GHG. Consistent with the findings of National Academies, 2017 and the economic literature, the IWG continued to conclude that the consumption rate of interest is the theoretically appropriate discount rate in an intergenerational context (IWG, 2010, 2013; 2016), and recommended that discount rate uncertainty and relevant aspects of intergenerational ethical considerations be accounted for in selecting future discount rates.[99] Furthermore, the damage estimates developed for use in the SC-GHG are estimated in consumption-equivalent terms, and so an application of OMB Circular A-4's guidance for regulatory analysis would then use the consumption discount rate to calculate the SC-GHG. As a member of the IWG involved in the development of the February 2021 SC-GHG TSD, EPA agrees with this assessment and will continue to follow developments in the literature pertaining to this issue. EPA also notes that while OMB Circular A-4, as published in 2003, recommends using 3 percent and 7 percent discount rates as “default” values, Circular A-4 also reminds agencies that "different regulations may call for different emphases in the analysis, depending on the nature and complexity of the regulatory issues and the sensitivity of the benefit and cost estimates to the key assumptions." On discounting, Circular A-4 recognizes that "special ethical considerations arise when comparing benefits and costs across generations,” and Circular A-4 acknowledges that analyses may appropriately "discount future costs and consumption benefits…at a lower rate than for intragenerational analysis." In the 2015 Response to Comments on the Social Cost of Carbon for Regulatory Impact Analysis, OMB, EPA, and the other IWG members recognized that “Circular A-4 is a living document” and “the use of 7 percent is not considered appropriate for intergenerational discounting. There is wide support for this view in the academic literature, and it is recognized in Circular A-4 itself.” Thus, EPA concludes that a 7 percent discount rate is not appropriate to apply to value the social cost of greenhouse gases in the analysis presented in this analysis. In this analysis, to calculate the present and annualized values of climate benefits, EPA uses the same discount rate as the rate used to discount the value of damages from future GHG emissions, for internal consistency. That approach to discounting follows the same approach that the February 2021 SC-GHG TSD recommends “to ensure internal consistency—*i.e.*, future damages from climate change using the SC-GHG at 2.5 percent should be discounted to the base year of the analysis using the same 2.5 percent rate.” EPA has also consulted the National Academies' 2017 recommendations on how SC-GHG estimates can "be combined in RIAs with other cost and benefits estimates that may use different discount rates.” The National Academies reviewed “several options,” including "presenting all discount rate combinations of other costs and benefits with [SC-GHG] estimates.”

While the IWG works to assess how best to incorporate the latest, peer reviewed science to develop an updated set of SC-GHG estimates, it recommends the interim estimates to be the most recent estimates developed by the IWG prior to the group being disbanded in 2017. The estimates rely on the same models and harmonized inputs and are calculated using a range of discount rates. As explained in the February 2021 SC-GHG TSD, the IWG has concluded that it is appropriate for agencies to revert to the same set of four values drawn from the SC-GHG distributions based on three discount rates as were used in regulatory analyses between 2010 and 2016 and subject to public comment. For each discount rate, the IWG combined the distributions across models and socioeconomic emissions scenarios (applying equal weight to each) and then

[99] GHG emissions are stock pollutants, with damages associated with what has accumulated in the atmosphere over time, and they are long lived such that subsequent damages resulting from emissions today occur over many decades or centuries depending on the specific greenhouse gas under consideration. In calculating the SC-GHG, the stream of future damages to agriculture, human health, and other market and non-market sectors from an additional unit of emissions are estimated in terms of reduced consumption (or consumption equivalents). Then that stream of future damages is discounted to its present value in the year when the additional unit of emissions was released. Given the long time horizon over which the damages are expected to occur, the discount rate has a large influence on the present value of future damages.

selected a set of four values for use in benefit-cost analyses: an average value resulting from the model runs for each of three discount rates (2.5 percent, 3 percent, and 5 percent), plus a fourth value, selected as the 95th percentile of estimates based on a 3 percent discount rate. The fourth value was included to provide information on potentially higher-than-expected economic impacts from climate change, conditional on the 3 percent estimate of the discount rate. As explained in the February 2021 SC-GHG TSD, and EPA agrees, this update reflects the immediate need to have an operational SC-GHG for use in regulatory benefit-cost analyses and other applications that was developed using a transparent process, peer-reviewed methodologies, and the science available at the time of that process. Those estimates were subject to public comment in the context of dozens of proposed rulemakings as well as in a dedicated public comment period in 2013.

Table 8-6 presents the interim SC-$CO_2$ estimates across all the model runs for each discount rate for emissions occurring in 2025 to 2049. These estimates are reported in 2021 dollars but are otherwise identical to those presented in the IWG's 2016 TSD (IWG, 2016). For purposes of capturing uncertainty around the SC-$CO_2$ estimates in analyses, the IWG's February 2021 SC-GHG TSD emphasizes the importance of considering all four of the SC-$CO_2$ values. The SC-$CO_2$ increases over time within the models — *i.e.*, the societal harm from one metric ton emitted in 2030 is higher than the harm caused by one metric ton emitted in 2025 — because future emissions produce larger incremental damages as physical and economic systems become more stressed in response to greater climatic change, and because GDP is growing over time and many damage categories are modeled as proportional to GDP. EPA estimated the climate benefits of the net $CO_2$ emission reductions for each analysis year between 2025 and 2049 by applying the annual SC-$CO_2$ estimates, shown in Table 8-6, to the estimated changes in $CO_2$ emissions in the corresponding year under the regulatory options. EPA then calculated the present value and annualized value of climate benefits as of the expected rule promulgation year of 2024 by discounting each year-specific value to the year 2024 using the same rate used to calculate the corresponding SC-$CO_2$.

**Table 8-6: Interim Estimates of the Social Cost of Carbon, 2025 – 2049 (2021$/Metric Tonne $CO_2$)**

| | Discount Rate and Statistic | | | |
|---|---|---|---|---|
| **Year** | **5% Average** | **3% Average** | **2.5% Average** | **3% 95th percentile** |
| 2025 | $18 | $59 | $87 | $177 |
| 2026 | $18 | $60 | $88 | $180 |
| 2027 | $19 | $61 | $89 | $184 |
| 2028 | $19 | $62 | $91 | $188 |
| 2029 | $20 | $63 | $92 | $191 |
| 2030 | $20 | $65 | $93 | $195 |
| 2031 | $21 | $66 | $95 | $199 |
| 2032 | $21 | $67 | $96 | $203 |
| 2033 | $22 | $68 | $98 | $207 |
| 2034 | $23 | $69 | $99 | $211 |
| 2035 | $23 | $70 | $101 | $215 |
| 2036 | $24 | $72 | $102 | $219 |
| 2037 | $24 | $73 | $103 | $223 |
| 2038 | $25 | $74 | $105 | $227 |
| 2039 | $26 | $75 | $106 | $231 |
| 2040 | $26 | $76 | $108 | $235 |
| 2041 | $27 | $78 | $109 | $239 |
| 2042 | $28 | $79 | $111 | $242 |
| 2043 | $28 | $80 | $112 | $246 |
| 2044 | $29 | $81 | $113 | $250 |
| 2045 | $30 | $82 | $115 | $253 |

**Table 8-6: Interim Estimates of the Social Cost of Carbon, 2025 – 2049 (2021$/Metric Tonne $CO_2$)**

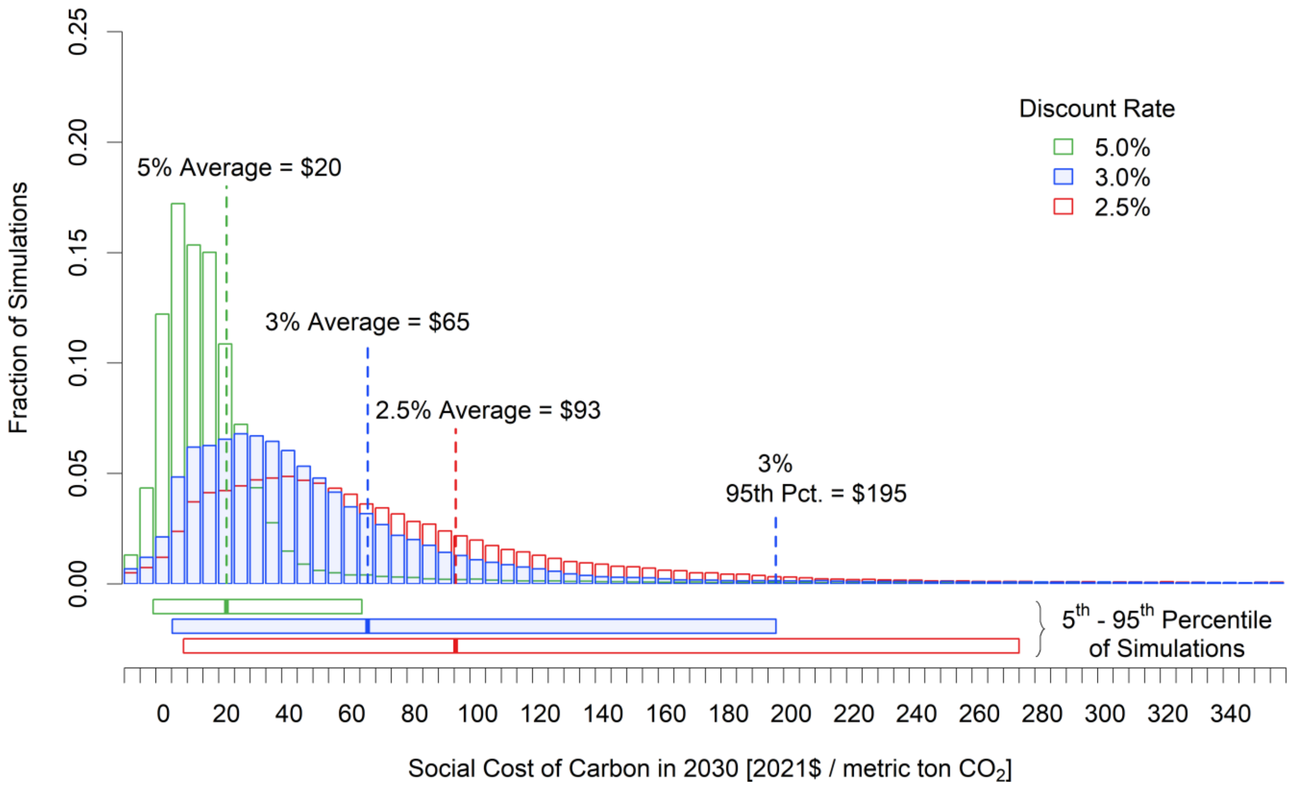
| | Discount Rate and Statistic | | | |
|---|---|---|---|---|
| **Year** | **5% Average** | **3% Average** | **2.5% Average** | **3% 95th percentile** |
| 2046 | $30 | $84 | $116 | $257 |
| 2047 | $31 | $85 | $117 | $261 |
| 2048 | $32 | $86 | $119 | $264 |
| 2049 | $32 | $87 | $120 | $268 |

Note: These SC-$CO_2$ values are identical to those reported in the 2016 TSD (IWG, 2016b) and February 2021 TSD (IWG, 2021) adjusted for inflation to 2021 dollars using the annual GDP Implicit Price Deflator values in the U.S. Bureau of Economic Analysis' (BEA) NIPA Table 1.1.9 (U.S. BEA, 2022), which are 118.895 and 92.642, respectively for 2021 and 2007. SC-$CO_2$ values are stated in $/metric tonne $CO_2$, are rounded to the nearest dollar (1 metric tonne equals 1.102 short tons) and vary depending on the year of $CO_2$ emissions.

*Source: U.S. EPA Analysis, 2022 based on IWG, 2016)*

There are a number of limitations and uncertainties associated with the SC-$CO_2$ estimates presented in Table 8-6. Some uncertainties are captured within the analysis, while other areas of uncertainty have not yet been quantified in way that can by modeled. Figure 8-1 presents the quantified sources of uncertainty in the form of frequency distributions for the SC-$CO_2$ estimates for emissions in 2030. The distribution of SC-$CO_2$ estimates reflect uncertainty in key model parameters such as the equilibrium climate sensitivity, as well as uncertainty in other parameters set by the original model developers. To highlight the difference between the impact of the discount rate 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 for each discount rate. As illustrated by the figure, the assumed discount rate plays a critical role in the ultimate estimate of the SC-$CO_2$. This is because GHG 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. As discussed in the February 2021 SC-GHG TSD, there are other sources of uncertainty that have not yet been quantified and are thus not reflected in these estimates.

**Figure 8-1: Frequency Distribution of Interim SC-$CO_2$ Estimates for 2030 (in 2021$ per Metric Ton $CO_2$)[100]**




The interim SC-$CO_2$ estimates presented in Table 8-6 have a number of limitations. First, the current scientific and economic understanding of discounting approaches suggests discount rates appropriate for intergenerational analysis in the context of climate change are likely to be less than 3 percent, near 2 percent or lower (IWG, 2021). Second, the IAMs used to produce these interim estimates do not include all of the important physical, ecological, and economic impacts of climate change recognized in the climate change literature and the science underlying their "damage functions" — *i.e.*, the core parts of the IAMs that map global mean temperature changes and other physical impacts of climate change into economic (both market and nonmarket) damages — lags behind the most recent research. For example, limitations include the incomplete treatment of catastrophic and non-catastrophic impacts in the integrated assessment models, 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. Likewise, the socioeconomic and emissions scenarios used as inputs to the models do not reflect new information from the last decade of scenario generation or the full range of projections.

The modeling limitations do not all work in the same direction in terms of their influence on the SC-$CO_2$ estimates. However, the IWG has recommended that, taken together, the limitations suggest that the interim

[100] Although the distributions and numbers in Figure 8-1 are based on the full set of model results (150,000 estimates for each discount rate and gas), for display purposes the horizontal axis is truncated with 0.47 to 0.89 percent of the estimates falling below the lowest bin displayed and 0.31 to 3.66 percent of the estimates falling above the highest bin displayed, depending on the discount rate.

SC-$CO_2$ estimates used in this proposed rule likely underestimate the damages from $CO_2$ emissions. In particular, the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (IPCC, 2007), which was the most current IPCC assessment available at the time when the IWG decision over the ECS input was made, concluded that SC-$CO_2$ estimates "very likely…underestimate the damage costs" due to omitted impacts. Since then, the peer-reviewed literature has continued to support this conclusion, as noted in the IPCC's Fifth Assessment report (IPCC, 2014) and other recent scientific assessments (*e.g.*, IPCC, 2018, 2019a; 2019b); U.S. Global Change Research Program (USGCRP, 2016, 2018); and the National Academies of Sciences, Engineering, and Medicine (National Academies, 2017, 2019). These assessments confirm and strengthen the science, updating projections of future climate change and documenting and attributing ongoing changes. For example, sea level rise projections from the IPCC's Fourth Assessment report ranged from 18 to 59 centimeters by the 2090s relative to 1980-1999, while excluding any dynamic changes in ice sheets due to the limited understanding of those processes at the time (IPCC, 2007). A decade later, the Fourth National Climate Assessment projected a substantially larger sea level rise of 30 to 130 centimeters by the end of the century relative to 2000, while not ruling out even more extreme outcomes (U.S. Global Change Research Program, 2018). EPA has reviewed and considered the limitations of the models used to estimate the interim SC-GHG estimates, and concurs with the February 2021 SC-GHG TSD's assessment that, taken together, the limitations suggest that the interim SC-$CO_2$ estimates likely underestimate the damages from $CO_2$ emissions. The February 2021 SC-GHG TSD briefly previews some of the recent advances in the scientific and economic literature that the IWG is actively following and that could provide guidance on, or methodologies for, addressing some of the limitations with the interim SC-$CO_2$ estimates. The IWG is currently working on a comprehensive update of the SC-GHG estimates taking into consideration recommendations from the National Academies of Sciences, Engineering and Medicine, recent scientific literature, public comments received on the February 2021 TSD and other input from experts and diverse stakeholder groups (National Academies, 2017). While that process continues, EPA is continuously reviewing developments in the scientific literature on the SC-GHG, including more robust methodologies for estimating damages from emissions, and looking for opportunities to further improve SC-GHG estimation going forward. Most recently, EPA presented a draft set of updated SC-GHG estimates within a sensitivity analysis in the regulatory impact analysis of EPA's November 2022 supplemental proposal for oil and gas standards that that aims to incorporate recent advances in the climate science and economics literature. Specifically, the draft updated methodology incorporates new literature and research consistent with the National Academies near-term recommendations on socioeconomic and emissions inputs, climate modeling components, discounting approaches, and treatment of uncertainty, and an enhanced representation of how physical impacts of climate change translate to economic damages in the modeling framework based on the best and readily adaptable damage functions available in the peer reviewed literature. EPA solicited public comment on the sensitivity analysis and the accompanying draft technical report, which explains the methodology underlying the new set of estimates, in the docket for the proposed Oil and Gas rule. EPA is also embarking on an external peer review of this technical report. More information about this process and public comment opportunities is available on EPA's website.[101] EPA's draft technical report will be among the many technical inputs available to the IWG as it continues its work.

### *8.2.2 Results*

Table 8-7 presents the undiscounted annual monetized climate benefits in selected years for Option 3, the proposed rule. Benefits are calculated using the four different estimates of the SC-$CO_2$ from Table 8-6 (model

[101] See https://www.epa.gov/environmental-economics/scghg

average at 2.5 percent, 3 percent, and 5 percent discount rates; and 95th percentile at 3 percent discount rate). Projected net $CO_2$ reductions each year are multiplied by the SC-$CO_2$ estimates for that year.

**Table 8-7: Estimated Undiscounted and Total Present Value of Climate Benefits from Changes in $CO_2$ Emissions under the Proposed Rule by SC-$CO_2$ Estimates, Compared to Baseline (Millions of 2021$)**

| Regulatory Option | Year | 3% Discount Rate (Average)[a, b] | 5% Discount Rate (Average)[a, b] | 2.5% Discount Rate (Average)[a, b] | 3% Discount Rate (95$^{th}$ Percentile)[a, b] |
|---|---|---|---|---|---|
| Option 3 (Proposed Rule) | 2028 | $42 | $13 | $61 | $130 |
| | 2030 | $280 | $86 | $400 | $830 |
| | 2035 | $670 | $220 | $960 | $2,100 |
| | 2040 | $500 | $170 | $700 | $1,500 |
| | 2045 | $890 | $320 | $1,200 | $2,700 |
| | 2049 | $230 | $87 | $320 | $720 |
| | Total present value (2025-2049)[c] | $2,000 | $7,900 | $12,000 | $24,000 |

a. Values rounded to two significant figures.

b. Climate benefits are based on changes $CO_2$ emissions and are calculated using four different estimates of the SC-$CO_2$ (model average at 2.5 percent, 3 percent, and 5 percent discount rates; and 95th percentile at 3 percent discount rate). The IWG emphasized the importance and value of considering the benefits calculated using all four estimates. As discussed in the Technical Support Document: Social Cost of Carbon, Methane, and Nitrous Oxide Interim Estimates under EO 13990 (IWG, 2021), a consideration of climate benefits calculated using discount rates below 3 percent, including 2 percent and lower, are also warranted when discounting intergenerational impacts.

c. The total present value is estimated by mapping IPM emissions changes to corresponding years within the period of analysis 2025-2049 based on Table 8-1 and assuming no changes in air emissions from electricity generation between 2025 and 2027. For trucking and energy use, EPA estimated changes in air emissions corresponding to the year each plant is estimated to implement changes in technology

*Source: U.S. EPA Analysis, 2022*

Table 8-8 shows the annualized climate benefits associated with changes in $CO_2$ emissions over the 2025-2049 period under each discount rate for the proposed rule by category of emissions. EPA annualized the climate benefits to enable consistent reporting across benefit categories (*e.g.*, benefits from improvement in water quality). As noted above, the IPM model run provides outputs starting in 2028. For the years 2025 through 2027, EPA assumed no change in air emissions from changes in the profile of electricity generation. For trucking and energy use, EPA estimated changes in air emissions corresponding to the year each plant is estimated to implement changes in technology. For each SC-$CO_2$ estimate, EPA then calculated the present value and annualized benefits from the perspective of 2024 by discounting each year-specific value to the year 2024 using the same discount rate used to calculate the SC-$CO_2$. Using the average SC-$CO_2$ value for the 3 percent discount rate and using a 3 percent discount to annualize the benefits yields annualized benefits of $440 million.

**Table 8-8: Estimated Total Annualized Climate Benefits from Changes in $CO_2$ Emissions under the Proposed Rule during the Period of 2025-2049 by Categories of Air Emissions and SC-$CO_2$ Estimates, Compared to Baseline (Millions of 2021$)**

| Regulatory Option | Category of Air Emissions | 3% Discount Rate (Average)[a] | 5% Discount Rate (Average)[a] | 2.5% Discount Rate (Average)[a] | 3% Discount Rate (95th Percentile)[a] |
|---|---|---|---|---|---|
| Option 3 (Proposed Rule) | Electricity Generation | $450 | $140 | $640 | $1,400 |
| | Trucking | -$0.24 | -$0.076 | -$0.35 | -$0.73 |
| | Energy use | -$7.1 | -$2.1 | -$10 | -$22 |
| | **Total** | **$440** | **$140** | **$630** | **$1,300** |

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

b. Climate benefits are based on changes $CO_2$ emissions and are calculated using four different estimates of the SC-$CO_2$ (model average at 2.5 percent, 3 percent, and 5 percent discount rates; and 95th percentile at 3 percent discount rate). The IWG emphasized the importance and value of considering the benefits calculated using all four estimates. As discussed in the Technical Support Document: Social Cost of Carbon, Methane, and Nitrous Oxide Interim Estimates under EO 13990 (IWG, 2021), a consideration of climate benefits calculated using discount rates below 3 percent, including 2 percent and lower, are also warranted when discounting intergenerational impacts.

*Source: U.S. EPA Analysis, 2022*

As discussed above, the IWG is currently working on a comprehensive update of the SC-GHG estimates under EO 13990 taking into consideration recommendations from the National Academies of Sciences, Engineering and Medicine, recent scientific literature, and public comments received on the February 2021 SC-GHG TSD. EPA is a member of the IWG and is participating in the IWG's review and updating process under EO 13990.

## 8.3 Human Health Benefits

### *8.3.1 Data and Methodology*

As summarized in Table 8-5, the proposed 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 alters the ambient concentrations, which in turn leads to changes in population exposure. EPA estimated the changes in the human health impacts associated with $PM_{2.5}$ and ozone.[102]

This section summarizes EPA's approach to estimating the incidence and economic value of the $PM_{2.5}$ and ozone-related benefits estimated for Option 3. The approach entails two major steps: (1) developing baseline and Option 3 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 3 as compared to the baseline. In this approach, EPA used IPM projections of EGU air emissions for the baseline and Option 3 (proposed rule).

102 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, 2016b, 2017b)

#### 8.3.1.1 Air Quality Modeling Methodology

As described in *Appendix I*, spatial fields of annual ozone and $PM_{2.5}$ concentrations representing the baseline and Option 3 were obtained from ozone source apportionment modeling that was performed as part of the *Regulatory Impact Analysis for the proposed Federal Implementation Plan Addressing Regional Ozone Transport for the 2015 Ozone National Ambient Air Quality Standard* (U.S. EPA, 2022c) and from PM source apportionment modeling performed for this proposed 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 proposed rule.

EPA prepared spatial fields of air quality for the baseline and the Option 3 for two health-impact metrics: annual mean $PM_{2.5}$ and April through September seasonal average 8-hour daily maximum (MDA8) ozone (AS-MO3). The EGU emissions for the baseline and Option 3, consisting of total $NO_X$, $SO_2$, and primary $PM_{2.5}$ emissions summarized by year and state, were obtained from the outputs of the IPM run, as described above and in Chapter 5 of the RIA (U.S. EPA, 2023c). As such, the spatial fields do not account for changes in emissions associated with power requirements to operate treatment systems or with transportation. See Section 8.3.1 regarding limitations and uncertainty associated with the analysis of air quality related benefits.

The basic methodology for determining air quality changes is the same as that used in the RIAs from multiple previous rules (U.S. EPA, 2019g; 2020b; 2020a, 2021b; 2022c). *Appendix I* provides an overview of the air quality modeling and the methodologies EPA used to develop spatial fields of seasonal ozone and annual $PM_{2.5}$ concentrations. The appendix also provides selected figures showing the geographical and temporal distribution of air quality changes.

EPA used air quality modeling to estimate health benefits associated with changes in ozone and $PM_{2.5}$ concentrations that may occur because of Option 3 of the proposed rule relative to the baseline, with the air quality 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.[103] While the air quality modeling 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 proposed 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 proposed 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 Option 3 for the proposed rule using the open-source environmental Benefits Mapping and Analysis Program—Community Edition (BenMAP-CE) (Sacks *et al.*, 2018). The *Estimating $PM_{2.5}$- and Ozone-Attributable Health Benefits* Technical Support Document (TSD) fully describes the Agency's approach for identifying those health endpoints to evaluate as well as quantifying their number and value (U.S. EPA, 2023e). In the TSD, the reader can find the rationale for selecting health endpoints to

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103 The air quality modeling techniques used for this analysis reflect non-EGU emissions as of 2026, so implementation or effects of any changes in non-EGU emissions expected to occur after 2026 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.

quantify; the demographic, health and economic data used; modeling assumptions; and our techniques for quantifying uncertainty.

Estimating the health benefits of reductions in $PM_{2.5}$ and ozone exposure begins with estimating the change in exposure for each individual and then estimating the change in each individual's risks for those health outcomes affected by exposure. The dollar benefit of reducing the risk of each adverse effect is based on the exposed individual's willingness to pay (WTP) for the risk change, assuming that each outcome is independent of one another. The greater the magnitude of the risk reduction from a given change in concentration, the greater the individual's WTP, all else equal. The social benefit of the change in health risks equals the sum of the individual WTP estimates across all of the affected individuals residing in the United States. We conduct this analysis by adapting primary research—specifically, air pollution epidemiology studies and economic value studies—from similar contexts. This approach is sometimes referred to as "benefits transfer." Below we describe the procedure we follow for: (1) selecting air pollution health endpoints to quantify; (2) calculating counts of air pollution effects using a health impact function; (3) specifying the health impact function with concentration-response parameters drawn from the epidemiological literature.

The BenMAP-CE tool quantifies the number and value of air pollution-attributable premature deaths and illnesses resulting from changes in $PM_{2.5}$ and ozone concentrations. Table 8-9 reports the ozone and $PM_{2.5}$-related human health impacts effects EPA quantified and those the Agency did not quantify in this analysis of Option 3 of the proposal. The list of benefit categories not quantified is not exhaustive. And, among the effects quantified, it might not have been possible to quantify completely either the full range of human health impacts or economic values.

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

| 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 65-99 or age 30-99) | ✓ | ✓ | PM ISA |
| | Infant mortality (age <1) | ✓ | ✓ | PM ISA |
| Morbidity from exposure to $PM_{2.5}$ | Heart attacks (age > 18) | ✓ | ✓ | PM ISA |
| | Hospital admissions—cardiovascular (ages 65-99) | ✓ | ✓ | PM ISA |
| | Emergency department visits— cardiovascular (age 0-99) | ✓ | ✓ | PM ISA |
| | Hospital admissions—respiratory (ages 0-18 and 65-99) | ✓ | ✓ | PM ISA |
| | Emergency room visits—respiratory (all ages) | ✓ | ✓ | PM ISA |
| | Cardiac arrest (ages 0-99; excludes initial hospital and/or emergency department visits) | ✓ | ✓ | PM ISA |
| | Stroke (ages 65-99) | ✓ | ✓ | PM ISA |
| | Asthma onset (ages 0-17) | ✓ | ✓ | PM ISA |
| | Asthma symptoms/exacerbation (6-17) | ✓ | ✓ | PM ISA |
| | Lung cancer (ages 30-99) | ✓ | ✓ | PM ISA |
| | Allergic rhinitis (hay fever) symptoms (ages 3-17) | ✓ | ✓ | PM ISA |
| | Lost work days (age 18-65) | ✓ | ✓ | PM ISA |
| | Minor restricted-activity days (age 18-65) | ✓ | ✓ | PM ISA |
| | Hospital admissions—Alzheimer's disease (ages 65-99) | ✓ | ✓ | PM ISA |
| | Hospital admissions—Parkinson's disease (ages 65-99) | ✓ | ✓ | PM ISA |
| | Other cardiovascular effects (*e.g.*, other ages) | — | — | PM ISA[b] |

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

| Category | Effect | Effect Quantified | Effect Monetized | More Information |
|---|---|---|---|---|
| | Other respiratory effects (*e.g.*, pulmonary function, non-asthma ER visits, non-bronchitis chronic diseases, other ages and populations) | — | — | PM ISA[b] |
| | Other nervous system effects (*e.g.*, autism, cognitive decline, dementia) | — | — | PM ISA[b] |
| | Metabolic effects (*e.g.*, diabetes) | — | — | PM ISA[b] |
| | Reproductive and developmental effects (*e.g.*, low birth weight, pre-term births) | — | — | PM ISA[b] |
| | Cancer, mutagenicity, and genotoxicity effects | — | — | PM ISA[b] |
| Mortality from exposure to ozone | Premature mortality based on short-term study estimates (age 0-99) | ✓ | ✓ | 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 (ages 0-99) | ✓ | ✓ | Ozone ISA |
| | Emergency department—respiratory (ages 0-99) | ✓ | ✓ | Ozone ISA |
| | Asthma onset (0-17) | ✓ | ✓ | Ozone ISA |
| | Asthma symptoms/exacerbation (asthmatics age 2-17) | ✓ | ✓ | Ozone ISA |
| | Allergic rhinitis (hay fever) symptoms (ages 3-17) | ✓ | ✓ | 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[b] |
| | Metabolic effects (*e.g.*, diabetes) | — | — | Ozone ISA[b] |
| | 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: EPA Analysis, 2022*

Counts of attributable effects are quantified using a health impact function, which combines information regarding the: concentration-response relationship between air quality changes and the risk of a given adverse outcome; population exposed to the air quality change; baseline rate of death or disease in that population; and air pollution concentration to which the population is exposed. When used to quantify $PM_{2.5}$- or ozone-related effects, the functions combine 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, associated with changes in estimated $PM_{2.5}$ or ozone concentrations (supplied using the IPM market model simulations described above), population data, and baseline death rates for each county in each year. After having quantified $PM_{2.5}$- and ozone-attributable cases of premature death and illness, EPA estimated the economic value of these cases using willingness to pay (WTP) and cost of illness (COI) measures.

EPA estimated the number of $PM_{2.5}$-attributable premature deaths using effect estimates from two epidemiology studies examining two large population cohorts: an analysis of Medicare beneficiaries (Wu *et al.*, 2020) and the National Health Interview Survey (NHIS) (Pope *et al.*, 2019). For ozone-related premature deaths, EPA uses one epidemiological study that examines the relationship between long-term exposure to ozone and mortality (Turner *et al.*, 2016) and two studies that examine the relationship between short-term exposure to ozone and mortality (Katsouyanni *et al.*, 2009; Zanobetti & Schwartz, 2008).

Projected impacts of the proposed rule (Option 3) 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 I* for details). Some portion of the air quality and health benefits from the proposed rule occur in areas not attaining the $PM_{2.5}$ or Ozone National Ambient Air Quality Standards (NAAQS). The analysis does not account for possible interactions between NAAQS compliance and the proposed rule, which introduces uncertainty into the benefits (and forgone benefits) estimates. If the proposed 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 proposed rule.

### *8.3.2 Results*

EPA reports below the estimated number of avoided $PM_{2.5}$ and ozone-related premature deaths and illnesses in each year for Option 3, the proposed rule, relative to the baseline along with the 95% confidence interval (see Table 8-10). The number of avoided premature deaths and illnesses under the proposed rule are calculated from the sum of individual reduced mortality and illness risk across the population in a given year. Table 8-11 reports the estimated economic value of avoided premature deaths and illness for each analysis year relative to the baseline along with the 95% confidence interval.

**Table 8-10: Estimated Avoided $PM_{2.5}$ and Ozone-Related Premature Deaths and Illnesses by Year for Option 3 of the Proposed Rule, Compared to Baseline (95% Confidence Interval)**

| Category and Basis | | 2028[a] | 2030[a] | 2035[a] | 2040[a] | 2045[a] | 2050[a] |
|---|---|---|---|---|---|---|---|
| **Avoided premature death among adults[b]** | | | | | | | |
| $PM_{2.5}$ | Wu et al. (2020) | 13 (11 to 14) | 24 (21 to 27) | 51 (45 to 57) | 41 (36 to 45) | 82 (72 to 91) | 60 (53 to 67) |
| | Pope III et al. (2019) | 28 (20 to 35) | 50 (36 to 63) | 100 (74 to 130) | 82 (58 to 100) | 160 (120 to 210) | 120 (84 to 150) |
| **Avoided infant mortality** | | | | | | | |
| $PM_{2.5}$ | Woodruff *et al.*, 2008 | 0.035 (-0.022 to 0.091) | 0.050 (-0.031 to 0.13) | 0.10 (-0.063 to 0.26) | 0.080 (-0.050 to 0.21) | 0.15 (-0.092 to 0.38) | 0.099 (-0.062 to 0.25) |
| Ozone ($O_3$) | Katsouyanni et al. (2009)[c,d] and Zanobetti et al. (2008)[d] pooled | 0.40 (0.16 to 0.63) | 0.92 (0.37 to 1.4) | 1.4 (0.55 to 2.2) | 0.78 (0.32 to 1.2) | 1.5 (0.61 to 2.4) | 0.69 (0.28 to 1.1) |
| | Turner et al. (2016)[c] | 8.8 (6.1 to 11) | 20 (14 to 26) | 30 (21 to 39) | 17 (12 to 23) | 33 (23 to 43) | 15 (11 to 20) |
| **All other morbidity effects** | | | | | | | |
| Acute Myocardial Infarcation | | 0.44 (0.26 to 0.62) | 0.84 (0.49 to 1.2) | 1.7 (1.0 to 2.4) | 1.4 (0.80 to 1.9) | 2.6 (1.5 to 3.7) | 2.0 (1.1 to 2.8) |
| Hospital admissions—cardiovascular ($PM_{2.5}$) | | 2.0 (1.5 to 2.6) | 3.6 (2.6 to 4.5) | 7.6 (5.5 to 9.6) | 6.0 (4.3 to 7.6) | 12 (8.6 to 15) | 8.7 (6.3 to 11) |
| Hospital admissions—respiratory ($PM_{2.5}$) | | 1.3 (0.43 to 2.1) | 2.3 (0.80 to 3.8) | 4.7 (1.6 to 7.7) | 3.9 (1.3 to 6.3) | 7.2 (2.4 to 12) | 5.3 (1.8 to 8.7) |
| Hospital admissions—respiratory[d] ($O_3$) | | 1.1 (-0.28 to 2.4) | 2.7 (-0.71 to 6.0) | 3.9 (-1.0 to 8.6) | 2.2 (-0.57 to 4.9) | 4.2 (-1.1 to 9.3) | 1.9 (-0.50 to 4.3) |
| Hospital admissions—Alzheimer's Disease ($PM_{2.5}$) | | 6.6 (4.9 to 8.2) | 12 (9.3 to 16) | 27 (20 to 34) | 24 (18 to 30) | 44 (33 to 55) | 33 (25 to 41) |
| Hospital admissions—Parkinson's Disease ($PM_{2.5}$) | | 0.83 (0.42 to 1.2) | 1.6 (0.81 to 2.4) | 3.3 (1.7 to 4.8) | 2.5 (1.3 to 3.7) | 4.9 (2.5 to 7.3) | 3.6 (1.8 to 5.4) |
| ED visits—cardiovascular ($PM_{2.5}$) | | 4.4 (-1.7 to 10) | 7.0 (-2.7 to 16) | 15 (-5.8 to 35) | 12 (-4.7 to 28) | 24 (-9.4 to 57) | 18 (-6.9 to 42) |
| ED visits—respiratory ($PM_{2.5}$) | | 9.4 (1.8 to 20) | 14 (2.7 to 29) | 28 (5.5 to 58) | 22 (4.3 to 45) | 46 (8.9 to 95) | 32 (6.4 to 68) |
| ED visits—respiratory[f] ($O_3$) | | 23 (6.3 to 48) | 46 (13 to 97) | 65 (18 to 140) | 33 (9.2 to 70) | 69 (19 to 140) | 32 (8.7 to 66) |
| Cardiac Arrest ($PM_{2.5}$) | | 0.21 (-0.086 to 0.48) | 0.35 (-0.14 to 0.80) | 0.73 (-0.30 to 1.6) | 0.57 (-0.23 to 1.3) | 1.1 (-0.46 to 2.6) | 0.82 (-0.33 to 1.9) |

**Table 8-10: Estimated Avoided $PM_{2.5}$ and Ozone-Related Premature Deaths and Illnesses by Year for Option 3 of the Proposed Rule, Compared to Baseline (95% Confidence Interval)**

| Category and Basis | 2028[a] | 2030[a] | 2035[a] | 2040[a] | 2045[a] | 2050[a] |
|---|---|---|---|---|---|---|
| Stroke ($PM_{2.5}$) | 0.87<br>(0.23 to 1.5) | 1.5<br>(0.38 to 2.5) | 3.0<br>(0.78 to 5.1) | 2.3<br>(0.59 to 3.9) | 4.5<br>(1.2 to 7.7) | 3.3<br>(0.85 to 5.6) |
| Lung Cancer ($PM_{2.5}$) | 0.96<br>(0.29 to 1.6) | 1.6<br>(0.50 to 2.7) | 3.5<br>(1.1 to 5.8) | 2.8<br>(0.85 to 4.7) | 5.7<br>(1.7 to 9.4) | 4.1<br>(1.2 to 6.9) |
| Hay Fever/Rhinitis ($PM_{2.5}$) | 190<br>(46 to 330) | 310<br>(74 to 530) | 670<br>(160 to 1,200) | 550<br>(130 to 950) | 1,100<br>(260 to 1,900) | 770<br>(180 to 1,300) |
| Hay Fever/Rhinitis[g] ($O_3$) | 380<br>(200 to 560) | 800<br>(420 to 1,200) | 1,100<br>(610 to 1,700) | 630<br>(330 to 920) | 1,200<br>(630 to 1,700) | 540<br>(280 to 780) |
| Asthma Onset ($PM_{2.5}$) | 30<br>(28 to 31) | 47<br>(45 to 49) | 100<br>(98 to 110) | 84<br>(80 to 87) | 160<br>(160 to 170) | 120<br>(110 to 120) |
| Asthma onset[e] ($O_3$) | 66<br>(57 to 75) | 140<br>(120 to 160) | 200<br>(170 to 220) | 110<br>(92 to 120) | 200<br>(170 to 230) | 91<br>(79 to 100) |
| Asthma symptoms-- Albuterol use ($PM_{2.5}$) | 4,000<br>(-1,900 to 9,700) | 6,500<br>(-3,200 to 16,000) | 14,000<br>(-6,900 to 34,000) | 11,000<br>(-5,500 to 28,000) | 22,000<br>(-11,000 to 55,000) | 16,000<br>(-7,800 to 39,000) |
| Asthma symptoms ($O_3$) | 12,000<br>(-1,500 to 26,000) | 26,000<br>(-3,200 to 54,000) | 37,000<br>(-4,500 to 76,000) | 20,000<br>(-2,500 to 42,000) | 37,000<br>(-4,700 to 79,000) | 17,000<br>(-2,100 to 35,000) |
| Minor restricted-activity days ($PM_{2.5}$) | 8,900<br>(7,200 to 11,000) | 14,000<br>(12,000 to 17,000) | 30,000<br>(24,000 to 36,000) | 25,000<br>(20,000 to 29,000) | 49,000<br>(40,000 to 59,000) | 36,000<br>(29,000 to 42,000) |
| Minor restricted-activity days[d,f] ($O_3$) | 6,000<br>(2,400 to 9,500) | 12,000<br>(4,800 to 19,000) | 17,000<br>(6,800 to 27,000) | 9,500<br>(3,800 to 15,000) | 19,000<br>(7,400 to 29,000) | 8,600<br>(3,400 to 14,000) |
| Lost work days ($PM_{2.5}$) | 1,500<br>(1,300 to 1,700) | 2,500<br>(2,100 to 2,800) | 5,100<br>(4,300 to 5,900) | 4,200<br>(3,500 to 4,800) | 8,400<br>(7,000 to 9,600) | 6,100<br>(5,100 to 7,000) |
| School absence days ($O_3$) | 4,400<br>(-620 to 9,200) | 9,200<br>(-1,300 to 19,000) | 13,000<br>(-1,900 to 28,000) | 7,200<br>(-1,000 to 15,000) | 14,000<br>(-1,900 to 29,000) | 6,200<br>(-870 to 13,000) |

a. Values rounded to two significant figures. Negative values indicate forgone benefits (*i.e.*, the number of avoided cases under the proposed 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.

c. Applied risk estimate derived from April-September exposures to estimates of ozone across the May-September warm season.

d. Converted ozone risk estimate metric from MDA1 to MDA8.

e. Applied risk estimate derived from June-August exposures to estimates of ozone across the May-September warm season.

f. Applied risk estimate derived from full year exposures to estimates of ozone across the May-September warm season.

g. Converted ozone risk estimate metric from DA24 to MDA8

*Source: U.S. EPA Analysis, 2022*

**Table 8-11: Estimated Discounted Economic Value of Avoided Ozone and $PM_{2.5}$-Attributable Premature Mortality and Illness for Option 3 of the Proposed Rule (95% Confidence Interval; millions of 2021$)**

| Year | 3% Discount Rate[a] | | | 7% Discount Rate[a] | | |
|---|---|---|---|---|---|---|
| 2028 | $160<br>($18 to $410) | *and* | $420<br>($42 to $1,100) | $140<br>($15 to $370) | *and* | $380<br>($36 to $1,000) |
| 2030 | $300<br>($35 to $780) | *and* | $820<br>($81 to $2,200) | $270<br>($29 to $700) | *and* | $730<br>($71 to $2,000) |
| 2035 | $640<br>($71 to $1,700) | *and* | $1,600<br>($160 to $4,200) | $570<br>($60 to $1,500) | *and* | $1,400<br>($140 to $3,800) |
| 2040 | $510<br>($55 to $1,300) | *and* | $1,200<br>($120 to $3,200) | $460<br>($48 to $1,200) | *and* | $1,100<br>($100 to $2,900) |
| 2045 | $1,100<br>($110 to $2,700) | *and* | $2,400<br>($240 to $6,500) | $940<br>($98 to $2,500) | *and* | $2,200<br>($210 to $5,900) |
| 2050 | $770<br>($81 to $2,000) | *and* | $1,700<br>($160 to $4,500) | $690<br>($71 to $1,800) | *and* | $1,500<br>($140 to $4,100) |

[a] Values rounded to two significant figures. The two benefits estimates are separated by the word "and" to signify that they are two separate estimates. The estimates do not represent lower- and upper-bound estimates and should not be summed.

*Source: U.S. EPA Analysis, 2022*

## 8.4 Annualized Air Quality-Related Benefits of Regulatory Options

EPA calculated the present value (discounted to 2024) of estimated air quality-related benefits over the analysis period of 2025-2049 and annualized these values to provide a measure that is comparable to the way other benefit categories and social costs are reported.

Sections 0 and 8.2.1 provide benefit estimates for Option 3, the proposed rule, based on the changes in the electricity generation profile projected in IPM. EPA mapped changes in emissions due to changes in electricity generation for each IPM run year to individual years within the analysis period of 2025-2049 (see Table 8-1). Because IPM outputs are available only for 2028 onward, EPA conservatively assumed no benefits associated with changes in the profile of electricity generation between 2025 and 2027. However, changes in the profile of electricity generation and EGU emissions are likely to occur as steam electric power generating plants start incurring costs to comply with the revised ELG between 2025 and 2029, and assuming no emission reductions for the first three years of this period understates the air quality-related benefits of the proposed rule.

For energy use and trucking, EPA estimated changes in air emissions corresponding to the year each plant is estimated to implement changes in technology. These emissions are included in the analysis of climate change benefits. As discussed in Section 8.3.1.1, however, 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 considered 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 8-4) but concluded that such an adjustment would have a negligible effect on the estimated human health benefit estimates given the comparably small emissions changes associated with power requirements and trucking. Therefore, EPA is presenting unadjusted values for the proposed rule below.

For the climate change benefits, EPA used the same discount rate used to develop SC-$CO_2$ values. For the human health benefits, EPA used 3 percent and 7 percent discounts.

**Table 8-12: Total Annualized Air Quality-Related Benefits of Proposed Rule (Option 3), Compared to the Baseline, 2025-2049 (Millions of 2021$)**

| SC-$CO_2$ | Climate Change Benefits[a] | $PM_{2.5}$ and Ozone Related Human Health Benefits at 3% Discount Rate[a] | Total | Climate Change Benefits[a] | $PM_{2.5}$ and Ozone Related Human Health Benefits at 7% Discount Rate | Total |
|---|---|---|---|---|---|---|
| 3% (Average) | $440 | $1,100 | **$1,540** | $440 | $840 | **$1,280** |
| 5% (Average) | $140 | $1,100 | **$1,240** | $140 | $840 | **$980** |
| 2.5% (Average) | $630 | $1,100 | **$1,730** | $630 | $840 | **$1,470** |
| 3% (95th Percentile) | $1,300 | $1,100 | **$2,400** | $1,300 | $840 | **$2,140** |

a. Values rounded to two significant figures.

b. Values calculated based on the LT mortality benefits estimates at 3 percent and 7 percent discount rates.

*Source: U.S. EPA Analysis, 2022*

Because EPA did not run IPM for Options 1, 2, and 4, EPA did not analyze climate and human health benefits for Options 1, 2, and 4. To provide insight into the potential air quality-related benefits across regulatory options, EPA estimated benefits for Options 1, 2, and 4 by scaling Option 3 benefits in proportion to the total social costs of the respective options (see BCA Chapter 11). Specifically, EPA calculated the ratio of the benefits to total social costs for Option 3, then multiplied total social costs for Options 1, 2, and 4 by this ratio. The scaling factor provides an approximation of the benefits by assuming proportionality between air-related benefits and total social costs.[104] While air-related benefits are expected to be driven primarily by changes in the profile of electricity generation (see Table 8-4 and Table 8-5) and the generation profile is affected most directly by the incremental technology implementation costs, the effects may not be linear.

Table 8-13 summarizes the annualized air quality-related benefits of the regulatory options for the climate change benefits estimated using the SC-$CO_2$ at 3 percent (average) and for human health benefits discounted using 3- and 7-percent discount rates.

**Table 8-13: Total Annualized Air Quality-Related Benefits of Regulatory Options Based on Extrapolation from Option 3, Compared to the Baseline, 2025-2049 (Millions of 2021$)**

| Regulatory Option | Climate Change Benefits (SC-$CO_2$ 3% Average) | $PM_{2.5}$ and Ozone Related Human Health Benefits at 3% Discount Rate[a] | Total | Climate Change Benefits (SC-$CO_2$ 3% Average) | $PM_{2.5}$ and Ozone Related Human Health Benefits at 7% Discount Rate[a] | Total |
|---|---|---|---|---|---|---|
| Option 1[b] | $190 | $500 | **$690** | $200.0 | $380 | **$580** |
| Option 2[b] | $370 | $950 | **$1,320** | $360.0 | $700 | **$1,060** |
| Option 3 (Proposed rule) | $440 | $1,100 | **$1,540** | $440.0 | $840 | **$1,280** |
| Option 4[b] | $450 | $1,200 | **$1,650** | $450.0 | $870 | **$1,320** |

a. Values rounded to two significant figures.

b. EPA estimated air quality-related benefits for Options 1, 2, and 4 by multiplying the total social costs for each option (see Section 11.2) by the ratio of [air quality-related benefits / total social costs] for Option 3.

social costs] for Option A

*Source: U.S. EPA Analysis, 2022*

## 8.5 Limitations and Uncertainties

Table 8-14 summarizes the limitations and uncertainties associated with the analysis of the air quality-related benefits. The second column of the table provides a conclusion of how the limitation affects the magnitude of the benefits estimate relative to expected actual benefits (*i.e.*, a source of uncertainty that has the effect of underestimating benefits indicates an expectation that expected actual benefits are larger than the estimate). The analysis also incorporates uncertainties associated with IPM modeling, which are discussed in Chapter 5 in the RIA (U.S. EPA, 2023c). See *Appendix I* for additional discussions of the uncertainty associated with the air quality modeling methodology.

**Table 8-14: Limitations and Uncertainties in Analysis of Air Quality-Related Benefits**

| Uncertainty/Limitation | Effect on Benefits Estimate | Notes |
|---|---|---|
| EPA extrapolated Option 3 benefits to Options 1, 2 and 4. | Uncertain | EPA ran IPM only for Option 3 and used the results to extrapolate benefits of Options 1, 2, and 4, based on the ratios of annualized benefits and annualized social costs. Air |

104 For the 2015 final rule, EPA analyzed two options using IPM and therefore had air-related benefits for both options. Using the benefit/cost ratio of one option to estimate benefits of the other option resulted in benefits that were ±7 percent than benefits derived from the IPM outputs.

**Table 8-14: Limitations and Uncertainties in Analysis of Air Quality-Related Benefits**

| Uncertainty/Limitation | Effect on Benefits Estimate | Notes |
|---|---|---|
| | | 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. Because benefits are dependent on magnitude and, for human health benefits, the spatial distribution of emissions changes, projected benefits for Options 1, 2, and 4 are uncertain. |
| EPA assumed no changes in air emissions associated with shifts in the mix of electricity generation in 2025-2027 | Underestimate | The first IPM year is 2028. Changes in the profile of electricity generation and EGU emissions are likely to occur as steam electric power generating plants start incurring costs to comply with the revised ELG between 2025 and 2029, and assuming no emission reductions for the first three years of this technology implementation period understates the air quality-related benefits of the proposed rule. This is even though the changes in air emissions predicted in IPM are modest in 2028. |
| The modeled air quality assumes a static apportionment of EGU sources and static emissions from other sources. | Uncertain | The profile of EGU and other emissions sources is expected to change over time. |
| 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 3. These projections do not include additional changes in $NO_X$ and $SO_2$ emissions associated with power requirements to operate wastewater treatment systems or trucking to transport CCR and other solid waste. While these emissions changes could affect human health benefit estimates, such effects are expected to be small overall given that these emissions generally represent less than 2 percent of total $NO_X$ and $SO_2$ emissions changes. |
| The methodology used to create ozone and $PM_{2.5}$ Air Quality surfaces do not account for nonlinear impacts of precursor emissions changes | Uncertain | *Appendix I* provides further details on this limitation. |
| All fine particles, regardless of their chemical composition, are equally potent in causing premature mortality. | Uncertain | The PM ISA concluded reaffirmed the conclusion reached in the 2009 ISA that “many PM2.5 components and sources are associated with many health effects and that the evidence does not indicate that any one source or component is consistently more strongly related with health effects than PM2.5 mass.” (U.S. EPA, 2009, 2022d). |

**Table 8-14: Limitations and Uncertainties in Analysis of Air Quality-Related Benefits**

| Uncertainty/Limitation | Effect on Benefits Estimate | Notes |
|---|---|---|
| Assumed "Cessation" lag between the change in $PM_{2.5}$ and ozone exposures and the total realization of changes in long-term 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 EPA's Science Advisory Board Health Effect Subcommittee (SAB-HES) (U.S. EPA, 2004). This distribution is also assumed for long-term mortality from ozone exposure. 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). Modeling used to estimate air quality changes from this proposed rule used meteorological fields representing conditions that occurred in 2016. |
| EPA did not analyze all benefits of changes in exposure to $NO_X$, $SO_2$, 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 benefits from changes in levels of $NO_X$, $SO_2$ and other air pollutants emitted by EGUs (*e.g.*, mercury, HCl). 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 Estimated Changes in Dredging Costs

As summarized in Table 3-1, the regulatory options could result in relatively 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).

## 9.1 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 2020 rule (U.S. EPA, 2020b).[105] 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.

### *9.1.1 Estimated Changes in Navigational Dredging Costs*

EPA identified 181 unique dredging jobs and 592 dredging occurrences[106] within the affected reaches. This corresponds to approximately 12 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 17 years across affected reaches and averaged 13.1 years. Dredging costs vary considerably across geographic locations and dredging jobs from less than $1 per cubic yard at Sardine

[105] For the 2020 rule analysis, EPA made two improvements to the methodology used in 2015. First, dredging occurrences were considered part of a single dredging job if the latitude and longitude coordinates were identical to within two decimal places. Second, the 10th percentile and 90th percentile of costs and sediment dredged for dredging occurrences within USACE districts were used to fill in missing values in the Low and High scenarios. EPA also 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*. This change was implemented to be more inclusive of the upstream impacts to affected COMIDs (*INC_TOTAL_YIELD* excluded upstream impacts). This analysis follows the 2020 approach.

[106] 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.

Point[107] in Louisiana to $485 per cubic yard at Herculaneum in St. Louis, Missouri.[108] The median unit cost of dredging for the entire conterminous United States is $3 per cubic yard.

Table 9-1 presents low and high estimates of dredged sediment volume and dredging costs during the period of 2025 through 2049 in navigational waterways that may be affected by steam electric plant discharges, based on historical averages. EPA generated low 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 $90.9 million to $183.0 million per year, using a 3 percent discount rate, and from $85.2 million to $181.8 million using a 7 percent discount rate.

**Table 9-1-: Estimated Annualized Navigational Dredging Costs at Affected Reaches Based on Historical Averages (Millions of 2021$)**

| Total Sediment Dredged (Millions Cubic Yards) | | Costs at 3% Discount Rate (Millions of 2021$ per Year) | | Costs at 7% Discount Rate (Millions of 2021$ per Year) | |
|---|---|---|---|---|---|
| Low | High | Low | High | Low | High |
| 727.7 | 1,320.5 | $90.9 | $183.0 | $85.2 | $181.8 |

*Source: U.S. EPA analysis, 2022.*

The difference between the estimated dredging costs using historical averages and costs resulting from the reduction in sediment deposition under a regulatory option as compared to baseline represents the avoided costs under the regulatory option. Table 9-2 presents estimated changes in navigational dredging costs for four regulatory options. Using a 3 percent discount rate, benefits range from $2,900 to $4,100 under Option 1 and from $4,300 to $5,800 under Options 2, 3, and 4. Using a 7 percent discount rate, benefits range from $2,600 to $3,900 under Option 1 and from $3,900 to $5,500 under Options 2, 3, and 4.

**Table 9-2: 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 (Millions of 2021$ per Year)[a] | | 7% Discount Rate (Millions of 2021$ per Year)[a] | |
|---|---|---|---|---|---|---|
| | Low | High | Low | High | Low | High |
| Option 1 | 9.0 | 14.1 | <$0.01 | <$0.01 | <$0.01 | <$0.01 |
| Option 2 | 12.0 | 17.9 | <$0.01 | $0.01 | <$0.01 | $0.01 |
| Option 3 | 12.1 | 18.1 | <$0.01 | $0.01 | <$0.01 | $0.01 |
| Option 4 | 12.1 | 18.2 | <$0.01 | $0.01 | <$0.01 | $0.01 |

a. Positive values represent cost savings.

*Source: U.S. EPA analysis, 2022.*

### *9.1.2 Estimated Changes in Reservoir Dredging Costs*

EPA identified 2,612 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 USACE district regional estimates of average dredging costs to calculate changes in

107 The cost per cubic yard at Sardine Point is $0.12.

108 The second most expensive dredging job was $79.50 per cubic yard at the Potomac River in Virginia.

reservoir dredging costs under the regulatory options. The median cost per cubic yard ranges from $0.34 in the Louisville USACE District (Kentucky) to $47.61 in the Rock Island USACE District (Illinois), with a median value of $8.16 for USACE districts which contain affected reservoirs. Table 9-3 presents low and high estimates of the projected volume of sediment to be dredged during the period of 2025 through 2049 from these reservoirs as well as estimated annualized dredging costs, based on historical averages. The estimated annualized reservoir dredging costs based on historical averages range between $704.3 million and $4,527.6 million using a 3 percent discount rate and $598.6 million and $4,325.2 million using a 7 percent discount rate.

**Table 9-3-: Estimated Annualized Reservoir Dredging Volume and Costs based on Historical Averages**

| Total Sediment Dredged (Millions Cubic Yards) | | Costs at 3% Discount Rate (Millions of 2021$ per Year) | | Costs at 7% Discount Rate (Millions of 2021$ per Year) | |
|---|---|---|---|---|---|
| Low | High | Low | High | Low | High |
| 6,968.5 | 41,810.9 | $704.3 | $4,527.6 | $598.6 | $4,325.2 |

*Source: U.S. EPA analysis, 2022.*

The difference between the estimated dredging costs using historical averages and costs resulting from the reduction in sediment deposition under a regulatory option as compared to baseline represents the avoided costs for that regulatory option. Table 9-4 presents avoided costs for reservoir dredging under the regulatory options, including low and high estimates. Using a 3 percent discount rate, benefits range from $500 to $600 under Option 1, from $600 to $700 under Option 2, and from $700 to $800 under Options 3 and 4. Using a 7 percent discount rate, benefits range from $500 to $600 under Options 1 and 2 and from $600 to $700 under Options 3 and 4.

**Table 9-4: Estimated Total Annualized Changes in Reservoir Dredging Volume and Costs under the Regulatory Options, Compared to Baseline**

| Regulatory Option | Total Reduction in Sediment Dredged (Thousands Cubic Yards) | | Costs at 3% Discount Rate[a] (Millions of 2021$ per Year) | | Costs at 7% Discount Rate[a] (Millions of 2021$ per Year) | |
|---|---|---|---|---|---|---|
| | Low | High | Low | High | Low | High |
| Option 1 | 2.2 | 2.5 | <$0.01 | <$0.01 | <$0.01 | <$0.01 |
| Option 2 | 2.5 | 2.9 | <$0.01 | <$0.01 | <$0.01 | <$0.01 |
| Option 3 | 2.7 | 3.0 | <$0.01 | <$0.01 | <$0.01 | <$0.01 |
| Option 4 | 2.7 | 3.0 | <$0.01 | <$0.01 | <$0.01 | <$0.01 |

a. Positive values represent cost savings.

*Source: U.S. EPA analysis, 2022.*

## 9.2 Limitation and Uncertainty

Table 9-5 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).

| 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 frequency of navigational dredging is based on the proximity of nearby dredging occurrences. | Uncertain | Because data in the U.S. Army Corps of Engineers Database does not indicate whether different dredging occurrences are part of a single dredging job, EPA determined whether dredging occurrences are part of a single dredging job by comparing their latitudinal and longitudinal coordinates to two decimal places. Changes in the precision of a job's coordinates would affect the number of occurrences that are considered part of the same dredging job. When precision is changed to a single decimal place, the number of occurrences that would be considered part of a single dredging job increases (and vice-versa). A larger (smaller) number of occurrences for a single dredging job would increase (decrease) the frequency of dredging and, as a result, total dredging costs over the period of analysis. |
| The analysis of navigational waterways includes only jobs reported for 1998 through 2015. | 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 64 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. |

# 10 Summary of Estimated Total Monetized Benefits

Table 10-1 and Table 10-2, 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 0 provide more detail on the estimation methodologies for each benefit category.

**Table 10-1: Summary of Estimated Total Annualized Benefits of the Regulatory Options, Compared to Baseline, at 3 Percent (Millions of 2021$)**

| Benefit Category | Option 1 | Option 2 | Option 3 | Option 4 |
|---|---|---|---|---|
| **Human Health** | **$3.4** | **$12.4** | **$12.7** | **$15.8** |
| Changes in IQ losses in children from exposure to lead[a] | <$0.01 | <$0.01 | $0.01 | $0.01 |
| Changes in IQ losses in children from exposure to mercury | $2.9 | $3.0 | $3.1 | $3.1 |
| Changes in cancer risk from disinfection by-products in drinking water | $0.5 | $9.4 | $9.6 | $12.7 |
| **Ecological Conditions and Recreational Uses Changes** | **$3.0** | **$3.8** | **$4.1** | **$4.3** |
| Use and nonuse values for water quality changes[b] | $3.0 | $3.8 | $4.1 | $4.3 |
| **Market and Productivity Effects[a]** | **<$0.01** | **<$0.01** | **<$0.01** | **<$0.01** |
| Changes in dredging costs[a] | <$0.01 | <$0.01 | <$0.01 | <$0.01 |
| **Air Quality-Related Effects[c]** | **$690** | **$1,320** | **$1,540** | **$1,650** |
| Climate change effects from changes in $CO_2$ emissions[c] | $190 | $370 | $440 | $450 |
| Human health effects from changes in $NO_X$, $SO_2$, and $PM_{2.5}$ emissions[c] | $500 | $950 | $1,100 | $1,200 |
| **Total[d]** | **$696.4** | **$1,336.2** | **$1,556.8** | **$1,670.1** |

a. "<$0.01" indicates that monetary values are greater than $0 but less than $0.01 million.

b. Estimates based on Model 1, which provides EPA's main estimate of non-market benefits. See Chapter 6 for details.

c. Values for air-quality related effects are rounded to two significant figures. EPA estimated the air quality-related benefits for Option 3. EPA extrapolated estimates of air quality-related benefits for Options 1, 2, and 4 from the estimate for Option 3 that is based on IPM outputs. See Chapter 8 for details.

d. Values for individual benefit categories may not sum to the total due to independent rounding.

*Source: U.S. EPA Analysis, 2022*

**Table 10-2: Summary of Estimated Total Annualized Benefits of the Regulatory Options, Compared to Baseline, at 7 Percent (Millions of 2021$)**

| Benefit Category | Option 1 | Option 2 | Option 3 | Option 4 |
|---|---|---|---|---|
| **Human Health** | **$0.8** | **$6.6** | **$6.8** | **$8.8** |
| Changes in IQ losses in children from exposure to lead[a] | <$0.01 | <$0.01 | <$0.01 | <$0.01 |
| Changes in IQ losses in children from exposure to mercury | $0.5 | $0.6 | $0.6 | $0.6 |
| Changes in cancer risk from disinfection by-products in drinking water | $0.3 | $6.1 | $6.2 | $8.3 |
| **Ecological Conditions and Recreational Uses Changes** | **$2.6** | **$3.3** | **$3.6** | **$3.7** |
| Use and nonuse values for water quality changes[b] | $2.6 | $3.3 | $3.6 | $3.7 |
| **Market and Productivity Effects[a]** | **<$0.01** | **<$0.01** | **<$0.01** | **<$0.01** |
| Changes in dredging costs[a] | <$0.01 | <$0.01 | <$0.01 | <$0.01 |
| **Air Quality-Related Effects[c]** | **$570** | **$1,070** | **$1,280** | **$1,320** |
| Climate change effects from changes in $CO_2$ emissions[c] | $190 | $370 | $440 | $450 |
| Human health effects from changes in $NO_X$, $SO_2$, and $PM_{2.5}$ emissions[c] | $380 | $700 | $840 | $870 |
| **Total[d]** | **$573.5** | **$1,080.0** | **$1,290.4** | **$1,332.6** |

a. "<$0.01" indicates that monetary values are greater than $0 but less than $0.01 million.

b. Estimates based on Model 1, which provides EPA's main estimate of non-market benefits. See Chapter 6 for details.

c. Values for air-quality related effects are rounded to two significant figures. EPA estimated the air quality-related benefits for Option 3. EPA extrapolated estimates of air quality-related benefits for Options 1, 2, and 4 from the estimate for Option 3 that is based on IPM outputs. See Chapter 8 for details.

d. Values for individual benefit categories may not sum to the total due to independent rounding.

*Source: U.S. EPA Analysis, 2022*

# 11 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, 2023c), EPA did not evaluate incremental baseline costs, and associated cost savings to state governments which would no longer have to evaluate and incorporate best professional judgment into NPDES permits under the regulatory options. Consequently, the only category of costs used to calculate social costs are estimated technology implementation costs for steam electric power plants.

## 11.1 Overview of Costs Analysis Framework

The RIA (Chapter 3) presents EPA's development of costs for the estimated 871 steam electric power plants within the scope of the proposed rule (U.S. EPA, 2023c). These costs (pre-tax) are used as the basis of the social cost analysis. A subset of these plants (69 to 93 plants, depending on the option) incur non-zero incremental costs under the regulatory options, as compared to the baseline.

As described earlier in Chapter 1, EPA estimated that steam electric power plants, in the aggregate, will implement control technologies between 2025 and 2029. For the analysis of social costs, EPA estimated a plant- and year-explicit schedule of technology implementation cost outlays over the period of 2025 through 2049.[109] 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. Specifically, EPA assumed that capital costs for compliance technology equipment, installation, site preparation, construction, and other upfront, non-annually recurring outlays associated with compliance with the regulatory options are incurred in the modeled compliance year for each plant. Annual fixed O&M costs, including regular annual monitoring, and annual variable O&M costs (*e.g.*, operating labor, maintenance labor and materials, electricity required to operate wastewater treatment systems, chemicals, combustion residual waste transport and disposal operation and maintenance) are incurred each year. Other non-annual recurring costs are incurred at specified intervals of 5, 6, or 10 years. See Section 3.1.2 in the RIA for details.

Following the approach used for the analyses of the 2015 and 2020 rules (U.S. EPA, 2015a, 2020b), after technology implementation costs were assigned to the year of occurrence, the Agency adjusted these costs for change between 2021 (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 2031; after these years, EPA assumed that the real change in prices is zero – that is, costs are expected to change in line with general

[109] The period of analysis extends through 2049 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 (2029).

inflation. EPA judges this to be a reasonable approach, given that capital expenditures will occur by 2029 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 anticipated rule promulgation year by discounting the cost in each year back to 2024, 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 two values of the discount rate, 3 percent and 7 percent, over a 25-year social cost analysis period. EPA assumed no re-installation of wastewater treatment technology during the period covered by the social cost analysis, *i.e.*, upfront capital costs are incurred only once.

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, 2023c 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 (see RIA Chapter 5) and relatively inelastic electricity demand with respect to price, at least in the short term (Burke and Abayasekara (2018); Bernstein and Griffin (2005)), 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.[110]

Finally, as discussed in Chapter 10 of the RIA (U.S. EPA, 2023c; 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 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.

## 11.2 Key Findings for Regulatory Options

Table 11-1 presents annualized incremental costs for the analyzed regulatory options, as compared to the baseline.

110 The specific assumptions of when each cost component is incurred can be found in Chapter 3 of the *RIA* (U.S. EPA, 2023c).

| Table 11-1: Summary of Estimated Incremental Annualized Costs for Regulatory Options (Millions of 2021$) | | |
|---|---|---|
| | **Annualized Costs** | |
| **Regulatory Option** | **3% Discount Rate** | **7% Discount Rate** |
| Option 1 | $88.4 | $96.6 |
| Option 2 | $167.0 | $180.4 |
| Option 3 | $200.3 | $216.5 |
| Option 4 | $207.2 | $224.1 |

*Source: U.S. EPA Analysis, 2022.*

Table 11-2 provides additional detail on the social cost calculations. The table compiles, for each regulatory option, the assumed time profiles of technology implementation costs incurred, relative to the baseline. 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 2025 through 2029, *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 11-2: Time Profile of Costs to Society (Millions of 2021$)**

| Year | Option 1 | Option 2 | Option 3 | Option 4 |
|---|---|---|---|---|
| 2025 | $157.9 | $206.4 | $256.4 | $262.6 |
| 2026 | $193.6 | $486.2 | $549.2 | $560.8 |
| 2027 | $172.1 | $270.1 | $362.9 | $362.9 |
| 2028 | $196.8 | $415.4 | $474.2 | $518.5 |
| 2029 | $276.0 | $392.4 | $471.6 | $488.3 |
| 2030 | $52.4 | $106.4 | $135.5 | $141.6 |
| 2031 | $54.9 | $109.8 | $138.4 | $144.6 |
| 2032 | $54.2 | $109.0 | $132.6 | $138.1 |
| 2033 | $54.1 | $109.0 | $132.6 | $138.1 |
| 2034 | $53.5 | $108.4 | $131.2 | $136.7 |
| 2035 | $54.0 | $108.9 | $130.6 | $136.1 |
| 2036 | $51.8 | $106.7 | $128.5 | $134.0 |
| 2037 | $53.5 | $108.3 | $130.1 | $135.6 |
| 2038 | $53.7 | $108.6 | $130.4 | $135.9 |
| 2039 | $52.6 | $107.5 | $128.2 | $130.4 |
| 2040 | $52.4 | $107.3 | $127.9 | $130.2 |
| 2041 | $53.3 | $108.2 | $128.8 | $131.1 |
| 2042 | $51.1 | $106.0 | $126.6 | $128.9 |
| 2043 | $52.9 | $107.7 | $128.4 | $130.7 |
| 2044 | $52.5 | $107.4 | $128.0 | $130.3 |
| 2045 | $52.4 | $106.7 | $126.1 | $128.4 |
| 2046 | $51.9 | $106.3 | $125.7 | $127.9 |
| 2047 | $52.2 | $106.5 | $125.9 | $128.2 |
| 2048 | $51.3 | $105.6 | $125.0 | $127.3 |
| 2049 | $51.4 | $105.7 | $125.1 | $127.4 |
| Annualized Costs, 3% | **$88.4** | **$167.0** | **$200.3** | **$207.2** |
| Annualized Costs, 7% | **$96.6** | **$180.4** | **$216.5** | **$224.1** |

*Source: U.S. EPA Analysis, 2022.*

# 12 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, 2023c).

## 12.1 Comparison of Benefits and Costs by Option

Chapters 10 and 11 present estimates of the benefits and costs, respectively, for the regulatory options as compared to the baseline. Table 12-1 presents EPA's estimates of benefits and costs of the regulatory options, at 3 percent and 7 percent discount rates, and annualized over 25 years.

**Table 12-1: Total Estimated Annualized Benefits and Costs by Regulatory Option and Discount Rate, Compared to Baseline (Millions of 2021$)**

| Regulatory Option | Total Monetized Benefits[a] | Total Costs |
|---|---|---|
| **3% Discount Rate** | | |
| Option 1 | $696 | $88.4 |
| Option 2 | $1,336 | $167.0 |
| Option 3 | $1,557 | $200.3 |
| Option 4 | $1,670 | $207.2 |
| **7% Discount Rate** | | |
| Option 1 | $573 | $96.6 |
| Option 2 | $1,080 | $180.4 |
| Option 3 | $1,290 | $216.5 |
| Option 4 | $1,333 | $224.1 |

a. EPA estimated the air quality-related benefits for Option 3. EPA extrapolated estimates of air quality-related benefits for Options 1, 2, and 4 from the estimate for Option 3 that is based on IPM outputs. See Chapter 8 for details.

*Source: U.S. EPA Analysis, 2022.*

## 12.2 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 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 12-2, all options have positive net annual monetized benefits, meaning benefits exceed costs. Net annual monetized benefit estimates range from $608 million under Option 1 to $1.5 billion under Option 4, using a 3 percent discount rate. Incremental net annual monetized benefit values are also positive across all options, which means that the increase in benefits under the more stringent options is larger than the increase in costs. Using a 3 percent discount rate, the incremental net annual monetized benefits of moving from Option 1 to Option 2 is $561 million, from Option 2 to Option 3 is $187 million, and from Option 3 to Option 4 is $106 million.

**Table 12-2: Analysis of Estimated Incremental Net Benefit of the Regulatory Options, Compared to Baseline and to Other Regulatory Options (Millions of 2021$)**

| Regulatory Option | Net Annual Monetized Benefits[a,b] | Incremental Net Annual Monetized Benefits[c] |
|---|---|---|
| **3% Discount Rate** | | |
| Option 1 | $608 | NA |
| Option 2 | $1,169 | $561.2 |
| Option 3 | $1,357 | $187.3 |
| Option 4 | $1,463 | $106.4 |
| **7% Discount Rate** | | |
| Option 1 | $477 | NA |
| Option 2 | $900 | $412.7 |
| Option 3 | $1,074 | $174.3 |
| Option 4 | $1,108 | $34.6 |

NA: Not applicable for Option 1

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 3. EPA extrapolated estimates of air quality-related benefits for Options 1, 2, and 4 from the estimate for Option 3 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, 2022.*

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# Appendix A Changes to Benefits Methodology since 2020 Final Rule Analysis

The table below summarizes the principal methodological changes EPA made to analyses of the benefits of the proposed rule regulatory options, as compared to the analyses of the 2020 final rule (U.S. EPA, 2020b).

**Table A-1: Changes to Benefits Analysis Since 2020 Final Rule**

| Benefits Category | Analysis Component [2020 final rule analysis value] | Changes to Analysis for regulatory options [2021 supplemental rule analysis value] |
|---|---|---|
| **General inputs and pollutant loads** | | |
| Universe of plants, EGUs, and receiving reaches | 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. | Analysis includes updates to the steam electric industry profile through the end of 2021, including the timing of projected retirements and refueling projects and existing treatment technologies. See TDD for details (U.S. EPA, 2023d). |
| General pollutant loadings and concentrations | Affected reaches based on immediate receiving reaches and flow paths in medium-resolution NHD. | Updated immediate receiving reaches (and associated downstream reaches) for selected plants. Discharges include CRL discharge outfalls. |
| | 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. | No change. |
| | 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. | The two analysis periods are 2025-2029 and 2030-2049. |
| 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 regional SPARROW models. | No change. |
| Population and socioeconomic characteristics | | 2019 ACS |
| **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. | Modeled changes in bromide concentrations in source water of public water systems and total trihalomethane concentrations in drinking water. |
| SDWIS database with PWS network and population served information | SDWIS 2020Q1 data | SDWIS 2021Q1 data |

**Table A-1: Changes to Benefits Analysis Since 2020 Final Rule**

| Benefits Category | Analysis Component [2020 final rule analysis value] | Changes to Analysis for regulatory options [2021 supplemental rule analysis value] |
|---|---|---|
| Lifetime changes in incidence of bladder cancer | 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. | Applied lifetime risk model to estimate changes in bladder cancer incidence in population served by public water systems. The modeling approach is generally the same EPA used for the 2019 proposed rule analysis. It is also consistent with that in a study by Weisman *et al.* (2022) which also applied the dose-response information from Regli *et al.* (2015) with more recent DBP data to estimate the potential number of bladder cancer cases associated with chlorination DBPs in drinking water. Weisman *et al.* (2022) found that the weight of evidence supporting causality further increased since Regli *et al.*, 2015. |
| Monetization of changes in incidence of bladder cancer | Because EPA did not calculate changes in incidence of bladder cancer, the Agency was unable to monetize this effect. | Mortality valued using VSL (U.S. EPA, 2010a). Morbidity valued based on COI (Greco *et al.*, 2019). |
| **Non-market benefits from water quality improvements** | | |
| WTP for water quality improvements | Benefits valued using a MRM | EPA added 10 new studies to the 2015 meta-data, revised existing observations as needed to improve consistency within the dataset, and re-estimated the MRM (see ICF, 2022 for details). Similar to the 2015 MRM, 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.<br><br>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. |

**Table A-1: Changes to Benefits Analysis Since 2020 Final Rule**

| Benefits Category | Analysis Component [2020 final rule analysis value] | Changes to Analysis for regulatory options [2021 supplemental rule analysis value] |
|---|---|---|
| **Air quality-related effects** | | |
| Emissions changes | 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. | Emissions from changes in electricity generation profile from 2022 IPM runs. Energy use-associated emissions were updated to reflect emission factors estimated using the 2022 IPM runs. |
| Air quality changes | Used the ACE modeling methodology to estimate changes in air pollutant concentrations. | Updated methodology to reflect the most recent air quality surfaces. |
| Monetization of health effects | Used BenMAP-CE model to estimate associated human health benefits. | No change. |
| Monetization of changes in $CO_2$ emissions | Used domestic-only SC-$CO_2$ values at 3 and 7 percent discounts. | Used global SC-$CO_2$ values at 2.5, 3 (average and 95%), and 5 percent discounts. |

# Appendix 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 10 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 2020 rule) SSC and TN and TP concentrations modeled in SPARROW at the medium-resolution NHD reach level.[111] 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 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.

[111] 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 subindex score.

**Table B-1: Freshwater Water Quality Subindices**

| Parameter | Concentrations | Concentration Unit | Subindex |
|---|---|---|---|
| **Dissolved Oxygen (DO)** | | | |
| **DO saturation ≤100%** | | | |
| DO | DO ≤ 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 ≥ 10.5 | mg/L | 100 |
| **100% < DO saturation ≤ 275%** | | | |
| DO | NA | mg/L | $100 \times \exp((DOsat - 100) \times -1.197 \times 10^{-2})$ |
| **275% < DO saturation** | | | |
| DO | NA | mg/L | 10 |
| **Fecal Coliform (FC)** | | | |
| FC | FC > 1,600 | cfu/100 mL | 10 |
| FC | 50 < FC ≤ 1,600 | cfu/100 mL | $98 \times \exp((FC - 50) \times -9.9178 \times 10^{-4})$ |
| FC | FC ≤ 50 | cfu/100 mL | 98 |
| **Total Nitrogen (TN)[a]** | | | |
| TN | $TN > TN_{10}$ | mg/L | a × exp(TN×b); where a and b are ecoregion-specific values |
| TN | $TN_{100} < TN \leq TN_{10}$ | mg/L | a × exp(TN×b); where a and b are ecoregion-specific values |
| TN | $TN \leq TN_{100}$ | mg/L | 100 |
| **Total Phosphorus (TP)[b]** | | | |
| TP | $TP > TP_{10}$ | mg/L | 10 |
| TP | $TP_{100} < TP \leq TP_{10}$ | mg/L | a × exp(TP×b); where a and b are ecoregion-specific values |
| TP | $TP \leq TP_{100}$ | mg/L | 100 |
| **Suspended Solids[c]** | | | |
| SSC | $SSC > SSC_{10}$ | mg/L | 10 |
| SSC | $SSC_{100} < SSC \leq SSC_{10}$ | mg/L | a × exp(SSC×b); where a and b are ecoregion-specific values |
| SSC | $SSC \leq SSC_{100}$ | mg/L | 100 |
| **Biochemical Oxygen Demand, 5-day (BOD)** | | | |
| BOD | BOD > 8 | mg/L | 10 |
| BOD | BOD ≤ 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, 2022, 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 (1/7$^{th}$ 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 Sediment 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 |
| ECOL3_46 | Aspen Parkland/Northern Glaciated Plains | 106.80 | -0.0005 | 121.8 | 4,382.1 |

| Table B-3: Suspended Sediment Subindex Curve Parameters, by Ecoregion | | | | | |
|---|---|---|---|---|---|
| **ID** | **Ecoregion Name** | **a** | **b** | **$SSC_{100}$** | **$SSC_{10}$** |
| 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 |
| ECOL3_03 | Willamette Valley | 124.45 | -0.626 | 0.35 | 4.03 |
| ECOL3_04 | Cascades | 140.20 | -4.890 | 0.07 | 0.54 |

**Table B-4: TN Subindex Curve Parameters, by Ecoregion**

| ID | Ecoregion Name | a | b | $TN_{100}$ | $TN_{10}$ |
|---|---|---|---|---|---|
| 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 |
| 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 |

**Table B-4: TN Subindex Curve Parameters, by Ecoregion**

| ID | Ecoregion Name | a | b | $TN_{100}$ | $TN_{10}$ |
|---|---|---|---|---|---|
| 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 |
| 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 |

**Table B-5: TP Subindex Curve Parameters, by Ecoregion**

| ID | Ecoregion Name | a | b | $TP_{100}$ | $TP_{10}$ |
|---|---|---|---|---|---|
| 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 |
| 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 |

**Table B-5: TP Subindex Curve Parameters, by Ecoregion**

| ID | Ecoregion Name | a | b | $TP_{100}$ | $TP_{10}$ |
|---|---|---|---|---|---|
| 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 |

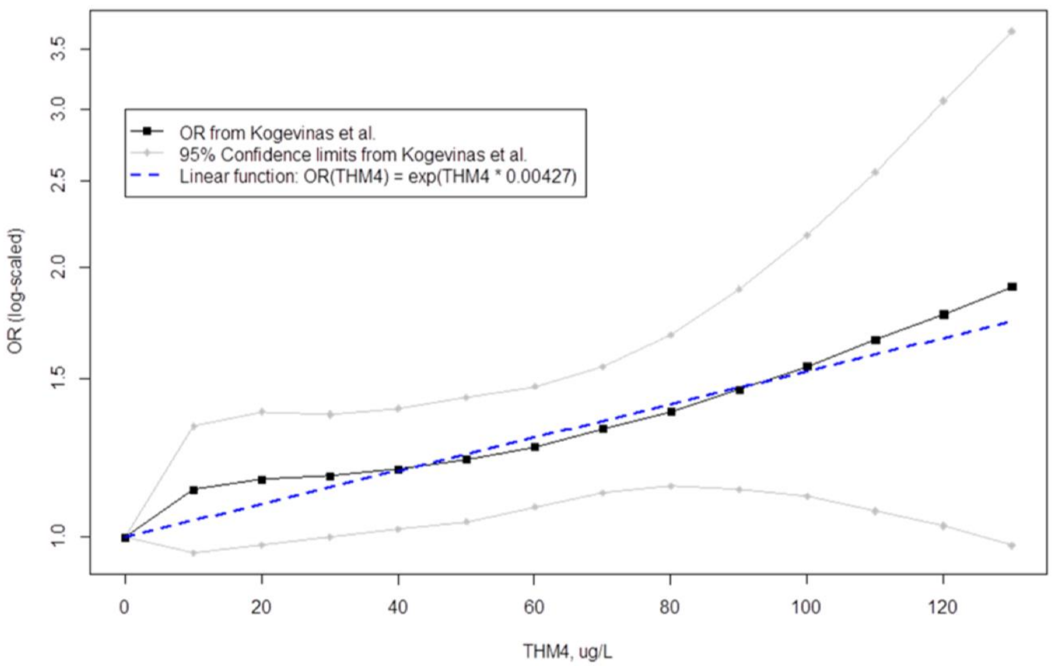
# Appendix C Additional Details on Modeling Change in Bladder Cancer Incidence from Change in TTHM Exposure

## C.1 Details on Life Table Approach

### *Health Impact Function*

Figure C-1 shows the dependence between lifetime odds of bladder cancer and drinking water TTHM concentration as reported by Villanueva *et al.* (2004). These data were used by Regli *et al.* (2015) to estimate the log-linear relationship in Equation 4-1, which is also displayed in Figure C-1. As described in *Chapter 4*, Regli *et al.* (2015) showed that, while the original analysis deviated from linearity, particularly at low doses, the overall pooled exposure-response relationship for TTHM could be well-approximated by a linear slope factor that predicted an incremental lifetime cancer risk of 1 in ten thousand exposed individuals ($10^{-4}$) per 1 µg/L increase in TTHM.[112]

**Figure C-1: Estimated Relationships between Lifetime Bladder Cancer Risk and TTHM Concentrations in Drinking Water**




*Source: Regli et al. (2015)*

EPA used the Regli *et al.* (2015) relationship between the lifetime odds of bladder cancer and lifetime TTHM exposure from drinking water to derive a set of age-specific health impact functions. A person's lifetime TTHM exposure from drinking water by age $a$—denoted by $x_a$—is defined as:

**Equation C-*1*.** $x_a = \frac{1}{a}\sum_{i=0}^{a-1} TTHM_i \, , x_0 = 0.$

112 Regli *et al.* (2015) addressed some of the limitations noted in the Hrudey *et al.* (2015) analysis. They suggested that the seeming discrepancy between the slope factor derived from the pooled epidemiological data and that from animal studies was due primarily to (1) potentially high human exposures to DBPs by the inhalation route, and (2) that trihalomethanes were acting as proxies for other carcinogenic DBPs.

See Table C-1at the end of this section for definitions of all variables used in the equations in this Appendix.

Assuming a baseline exposure of $z_a$ and a regulatory option exposure of $x_a$ (*i.e.*, exposure following implementation of a regulatory option), the relative risk (RR) of bladder cancer by age $a$ under the option exposure relative to the baseline exposure can be expressed as:

**Equation C-2.**

$$RR(x_a, z_a) = \left(\frac{O(x_a)}{O(z_a)}\right)^{-1} \cdot \left(LR_a \cdot \frac{O(x_a)}{O(z_a)} - LR_a + 1\right)$$

where $LR_a$ is the lifetime risk of bladder cancer within age interval $[0, a]$ (Fay et al. 2003) under baseline conditions.

Combining Equation C-1 and Equation C-2. shows that the relative risk of bladder cancer by age $a$ based on Regli *et al.* (2015) depends only on the lifetime risk and on the magnitude of change in TTHM concentration from baseline concentration, $\Delta x_a = x_a - z_a$, but not on the baseline TTHM level:

**Equation C-3.**

$$RR_{\text{Regli et al.}}(x_a, z_a) = \left(\frac{O(0) \cdot e^{0.00427 \cdot x_a}}{O(0) \cdot e^{0.00427 \cdot z_a}}\right)^{-1} \cdot \left(LR_a \cdot \frac{O(0) \cdot e^{0.00427 \cdot x_a}}{O(0) \cdot e^{0.00427 \cdot z_a}} - LR_a + 1\right)$$
$$= e^{-0.00427 \cdot (x_a - z_a)} \cdot \left(LR_a \cdot e^{0.00427 \cdot (x_a - z_a)} - LR_a + 1\right)$$
$$= e^{-0.00427 \cdot \Delta x_a} \cdot \left(LR_a \cdot e^{0.00427 \cdot \Delta x_a} - LR_a + 1\right).$$

At the average baseline TTHM concentration level of 38.05 μg/L reported in Regli *et al.* (2015), the slope of the Regli *et al.* (2015) relationship appears to be a good approximation of the slope of the piece-wise linear relationship implied by the Villanueva *et al.* (2004) data. For baseline TTHM levels in the 20 μg/L to 60 μg/L range, the Regli *et al.* (2015) slope is steeper than the slopes of the piece-wise linear relationship whereas for baseline TTHM levels above 60 μg/L the Regli *et al.* (2015) slope is flatter. While this potentially has implications for the magnitude of the health effects EPA modeled,[113] the relationship based on Villanueva *et al.* (2004) requires detailed information on the baseline TTHM exposure for the population of interest which is not available.

### *Health Risk Model*

To estimate the health effects of changes in TTHM exposure, the health risk model tracks evolution of two populations over time — the bladder cancer-free population and the bladder cancer population. These two populations are modeled for both the baseline annual TTHM exposure scenario and for the regulatory options TTHM exposure scenarios. Populations in the scenarios are demographically identical but they differ in the TTHM levels to which they are exposed. The population affected by change in bromide discharges associated with a regulatory option is assumed to be exposed to baseline TTHM levels prior to the regulatory option implementation year (in this case 2024) and to alternative TTHM levels that reflect the impact of technology implementation under each regulatory option starting in 2025.

113 If the piece-wise linear relationship based on Villanueva *et al.* (2004) reported data had been used as the basis for health impact function, there would have been larger effect estimates for some individuals and smaller effect estimates for others relative to the estimates obtained using the Regli *et al.* (2015) linear approximation.

To capture these effects while being consistent with the remainder of the cost-benefit framework, EPA modeled changes in health outcomes resulting from changes in exposure between 2025 and 2049. For these exposures, EPA modeled effects out to 2124 to capture the resultant lagged changes in lifetime bladder cancer risk, but did not attribute changes in bromide loadings and TTHM exposures to the regulatory options beyond 2049.[114]

EPA tracks mortality and bladder cancer experience for a set of model populations defined by sex, location, and age attained by 2025, which is denoted by $A = 0,1,2,3, \dots 100$. Each model population is followed from birth (corresponding to calendar year $2025 - A$) to age 100, using a one-year time step. Below, we first describe the process for quantifying the evolution of model population $A$ under the baseline TTHM exposure assumptions. We then describe the process for quantifying the evolution of the population under the regulatory option TTHM exposures. Finally, we describe the process for estimating the total calendar year $y$-specific health benefits which aggregate estimates over all model populations ($A = 0,1,2,3, \dots 100$).

**Evolution of Model Population *A* under Baseline TTHM Exposure**

Given a model population $A$, for each current age $a$ and calendar year $y$, the following baseline exposure $z_{a,y} = \frac{1}{a} \sum_{i=0}^{a-1} \text{Baseline TTHM}_{i,y-a+i}$ dependent quantities are computed:

- $l_{C=0,a,y}(z_{a,y})$: The number of bladder cancer-free living individuals at the beginning of age $a$, in year $y$;
- $d_{C=0,a,y}(z_{a,y})$: The number of deaths among bladder cancer-free individuals aged $a$ during the year $y$;
- $l_{C=1,a,y}(z_{a,y})$: The number of new bladder cancer cases among individuals aged $a$ during the year $y$.

To compute each quantity above, EPA makes an assumption about the priority of events that terminate a person's existence in the pool of bladder cancer-free living individuals. These events are general population deaths that occur with probability[115] $q_{C=0,a}$ and new bladder cancer diagnoses that occur with probability $\gamma_a$, which is approximated by age-specific annual bladder cancer incidence rate $IR_a \cdot 10^{-5}$. In the model, EPA assumes that the new cancer diagnoses occur after general population deaths and uses the following recurrent equations for ages $a > 0$:[116]

**Equation C-4.**

$$l_{C=0,a,y}(z_{a,y}) = l_{C=0,a-1,y-1}(z_{a-1,y-1}) - d_{C=0,a-1,y-1}(z_{a-1,y-1}) - l_{C=1,a-1,y-1}(z_{a-1,y-1})$$

114 This approach is equivalent to assuming that TTHM levels revert back to baseline conditions at the end of the regulatory option costing period.

115 The model does not index the general population death rates using the calendar year, because the model relies on the most recent static life tables.

116 EPA notes that this is a conservative assumption that results in a lower bound estimate of the policy impact (with respect to this particular uncertainty factor). An upper bound estimate of the policy impact can be obtained by assuming that new bladder diagnoses occur before general population deaths. In a limited sensitivity analysis, EPA found that estimates generated using this alternative assumption were approximately 5 percent larger than the estimates reported here.

**Equation C-5.** $$d_{C=0,a,y}(z_{a,y}) = q_{C=0,a} \cdot l_{C=0,a,y}(z_{a,y})$$

**Equation C-6.** $$l_{C=1,a,y}(z_{a,y}) = \gamma_a \cdot \left(l_{C=0,a,y}(z_{a,y}) - d_{C=0,a,y}(z_{a,y})\right)$$

To initiate each set of recurrent equations, EPA estimates the number of cancer-free individuals at age $a = 0$, denoted by $l_{C=0,0,y-A}(z_{0,y-A})$, that is consistent with the number of affected persons of age $A$ in 2025, denoted by $P$. To this end, Equation C-4, Equation C-5, and Equation C-6 are solved to find $l_{C=0,0,y-A}(z_{0,y-A})$ such that $l_{C=0,A,2025}(z_{A,2025}) = P$.

Consistent with available bladder cancer survival statistics, EPA models mortality experience in the bladder cancer populations $l_{C=1,a,y}(z_{a,y})$ as dependent on the age-at-onset $a$, disease duration $k$, and cancer stage $s$ (for bladder cancer there are four defined stages: localized, regional, distant, unstaged). Given each age-specific share of new cancer cases $l_{C=1,a,y}(z_{a,y})$ and age-specific share of new stage $s$ cancers $\delta_{S=s,a}$, EPA calculates the number of new stage $s$ cancers occurring at age $a$ in year $y$:

**Equation C-7.** $$\tilde{l}_{S=s,a,y,0}(z_{a,y}) = \delta_{S=s,a} \cdot l_{C=1,a,y}(z_{a,y})$$

For a model population aged $A$ years in 2025 and cancer stage $s$, EPA separately tracks $100 - A + 1$ new stage-specific bladder cancer populations from age-at-onset $a$ to age 100.[117] Next, a set of cancer duration $k$-dependent annual death probabilities is derived for each population from available data on relative survival rates[118] $r_{S=s,a,k}$ and general population annual death probabilities $q_{C=0,a+k}$ as follows:

**Equation C-8.** $$\tilde{q}_{S=s,a,k} = 1 - \frac{r_{S=s,a,k+1}}{r_{S=s,a,k}}\left(1 - q_{C=0,a+k}\right).$$

In estimating additional deaths in the cancer population in the year of diagnosis (*i.e.*, when $k = 0$), EPA accounts only for cancer population deaths that are in excess of the general population deaths. As such, the estimate of additional cancer population deaths is computed as follows:

**Equation C-9.** $$\tilde{d}_{S=s,a,y,0}(z_{a,y}) = \left(\tilde{q}_{S=s,a,0} - q_{C=0,a}\right) \cdot \tilde{l}_{S=s,a,y,0}(z_{a,y}),$$

In years that follow the initial diagnosis year (*i.e.*, $k > 0$), EPA uses the following recurrent equations to estimate the number of people living with bladder cancer and the annual number of deaths in the bladder cancer population:

**Equation C-10.** $$\tilde{l}_{S=s,a,y,k}(z_{a,y-k}) = \tilde{l}_{S=s,a,y,k-1}(z_{a,y-k}) - \tilde{d}_{S=s,a,y,k-1}(z_{a,y-k}),$$

---

[117] In total, there are $4 \cdot (100 - A + 1)$ new cancer populations being tracked for each model population.

[118] Note that $r_{S=s,a,k}$ is a multiplier that modifies the general probability of survival to age $k$ to reflect the fact that the population under consideration has developed cancer $k$ years ago.

**Equation C-11.** $\tilde{d}_{S=s,a,y,k}(z_{a,y-k}) = \tilde{q}_{S=s,a,k} \cdot \tilde{l}_{S=s,a,y,k}(z_{a,y-k})$.

Because EPA is interested in bladder cancer-related deaths rather than all deaths in the bladder cancer population, EPA also tracks the number of excess bladder cancer population deaths (*i.e.*, the number of deaths in the bladder cancer population over and above the number of deaths expected in the general population of the same age). The excess deaths are computed as:

**Equation C-12.** $\tilde{e}_{S=s,a,y,k}(z_{a,y-k}) = \tilde{q}_{S=s,a,k} \cdot \tilde{l}_{S=s,a,y,k}(z_{a,y-k}) - q_{C=0,a+k} \cdot \tilde{l}_{S=s,a,y,k}(z_{a,y-k})$

## Evolution of Model Population $A$ under the Regulatory Option TTHM Exposure

Under the baseline conditions when the change in TTHM is zero (*i.e.*, before 2025), EPA approximates the annual bladder cancer probability $\gamma_a$ by age-specific annual bladder cancer incidence rate $IR_a \cdot 10^{-5}$. As described in Section 4, current empirical evidence links TTHM exposure to the lifetime bladder cancer risk, rather than annual bladder cancer probability. EPA computes the TTHM-dependent annual new bladder cancer cases under the regulatory option conditions, $l_{C=1,a,y}(x_{a,y})$, in three steps. First, EPA recursively estimates $LR_{a,y}(z_{a,y})$, the lifetime risk of bladder cancer within age interval $[0, a]$ under the baseline conditions:

**Equation C-13.** $LR_{a,y}(z_{a,y}) = \frac{1}{l_{C=0,0,y-A}(z_{0,y-A})} \cdot \sum_{j=0}^{a-1} l_{C=1,j}(z_{j,y-A+j})$, $a > 0$ **and** $LR_{0,y-A}(z_{0,y-A}) = 0$

Second, the result of Equation C-13 is combined with the relative risk estimate $RR(x_{a,y}, z_{a,y})$, based on Regli *et al.* (2015):

**Equation C-14.** $LR_{a,y}(x_{a,y}) = RR(x_{a,y}, z_{a,y}) LR_{a,y}(z_{a,y})$

This results in a series of lifetime bladder cancer risk estimates under the option conditions. Third, EPA computes a series of new annual bladder cancer case estimates under the option conditions as follows:

**Equation C-15.** $l_{C=1,a,y}(x_{a,y}) = \left(LR_{a+1,y+1}(x_{a+1,y+1}) - LR_{a,y}(x_{a,y})\right) \cdot l_{C=0,0,y-A}(z_{0,y-A})$

## Health Effects and Benefits Attributable to Regulatory Options

To characterize the overall impact of the regulatory option in a given year $y$, for each model population defined by age $a$ in 2025, sex, and location, EPA calculates three quantities: the incremental number of new stage $s$ bladder cancer cases ($NC_{A,y,s}$), the incremental number of individuals living with stage $s$ bladder cancer ($LC_{A,y,s}$), and the incremental number of excess deaths in the bladder cancer population ($ED_{A,y}$). The formal definitions of each of these quantities are given below:

**Equation C- 16.**

$$NC_{A,y,s} = [0 \leq y - 2025 + A \leq 100] \cdot \left(\tilde{l}_{S=s,y-2025+A,y,0}(z_{y-2025+A,y}) - \tilde{l}_{S=s,y-2024+A,0}(x_{y-2025+A,y})\right)$$

**Equation C- 17.**

$$LC_{A,y,s} = \sum_{k=1}^{100} [0 \leq y - 2025 + A + k \leq 100] \cdot \left( \tilde{l}_{S=s,y-2025+A-k,y,k}\left(z_{y-2025+A-k,y-k}\right) - \tilde{l}_{S=s,y-2025+A-k,y,k}\left(x_{y-2025+A-k,y-k}\right) \right)$$

**Equation C- 18.**

$$ED_{A,y} = \sum_{k=0}^{100} [0 \leq y - 2025 + A + k \leq 100] \sum_{s \in S} \left( \tilde{e}_{S=s,y-2025+A-k,y,k}\left(z_{y-2025+A-k,y-k}\right) - \tilde{e}_{S=s,y-2025+A-k,y,k}\left(x_{y-2025+A-k,y-k}\right) \right)$$

These calculations are carried out to 2125, when those aged 0 years in 2025 attain the age of 100.

**Table C-1: Health Risk Model Variable Definitions**

| Variable | Definition |
|---|---|
| $O(x)$ | The odds of lifetime bladder cancer incident for an individual exposed to a lifetime average TTHM concentration in residential water supply of $x$ (ug/L) |
| $a$ | Current age or age at cancer diagnosis |
| $x_a$ | A person's lifetime option TTHM exposure by age $a$ |
| $z_a$ | A person's lifetime baseline TTHM exposure by age $a$ |
| $LR_a$ | Lifetime risk of bladder cancer within age interval $[0, a)$ under the baseline conditions |
| $IR_a$ | Age-specific baseline annual bladder cancer incidence rate |
| $RR(x_a, z_a)$ | Relative risk of bladder cancer by age $a$ given baseline exposure $z_a$ and option exposure $x_a$ |
| $A$ | Age in 2025 (years) |
| $y$ | Calendar year |
| $x_{a,y}$ | A person's lifetime option TTHM exposure by age $a$ given that this age occurs in year $y$ |
| $z_{a,y}$ | A person's lifetime baseline TTHM exposure by age $a$ given that this age occurs in year $y$ |
| $l_{C=0,a,y}(z_{a,y})$ | The baseline number of bladder cancer-free living individuals at the beginning of age $a$ given that this age occurs in year $y$ |
| $d_{C=0,a,y}(z_{a,y})$ | The baseline number of deaths among bladder cancer-free individuals at age $a$ given that this age occurs in year $y$ |
| $l_{C=1,a,y}(z_{a,y})$ | The baseline number of new bladder cancer cases at age $a$ given that this age occurs in year $y$ |
| $q_{C=0,a}$ | Probability of a general population death at age $a$ |
| $\gamma_a$ | Baseline probability of a new bladder cancer diagnosis at age $a$ given |
| $k$ | Bladder cancer duration in years |
| $s$ | Cancer stage (localized, regional, distant, unstaged) |
| $\delta_{S=s,a}$ | Age-specific share of new stage $s$ bladder cancers |
| $\tilde{l}_{S=s,a,y,0}(z_{a,y})$ | The baseline number of new stage $s$ cancers occurring at age $a$ given that this age occurs in year $y$ |
| $r_{S=s,a,k}$ | Relative survival rate $k$ years after stage $s$ bladder cancer occurrence at age $a$ |
| $\tilde{q}_{S=s,a,k}$ | Stage-specific probability of death in the bladder cancer population whose bladder cancer was diagnosed at age $a$ and they lived $k$ years after the diagnosis. Current age of these individuals is $a + k$. |
| $\tilde{d}_{S=s,a,y,0}(z_{a,y})$ | The baseline number of deaths in the stage $s$ cancer population in the year of diagnosis (*i.e.*, when $k = 0$), given the current age $a$ and the corresponding year $y$. |
| $\tilde{l}_{S=s,a,y,k}(z_{a,y-k})$ | The baseline number of living with the stage $s$ cancer in the $k$-th year after diagnosis in year $y$, given the cancer diagnosis at age $a$ and the cumulative exposure through to that age and year $y - k$. |

**Table C-1: Health Risk Model Variable Definitions**

| Variable | Definition |
|---|---|
| $\tilde{d}_{S=s,a,y,k}(z_{a,y-k})$ | The baseline number of deaths among those with the stage $s$ cancer in the $k$-th year after diagnosis in year $y$, given the cancer diagnosis at age $a$ and the cumulative exposure through to that age and year $y-k$. |
| $\tilde{e}_{S=s,a,y,k}(z_{a,y-k})$ | The baseline number of excess bladder cancer deaths (*i.e.*, the number of deaths in the bladder cancer population over and above the number of deaths expected in the general population of the same age) among those with the stage $s$ cancer in the $k$-th year after diagnosis in year $y$, given the cancer diagnosis at age $a$ and the cumulative exposure through to that age and year $y-k$. |
| $LR_{a,y}(z_{a,y})$ | Recursive estimate of the lifetime risk of bladder cancer within age interval [0, $a$) under the baseline conditions, given that age $a$ occurs in year $y$ |
| $RR(x_{a,y}, z_{a,y})$ | Relative risk of bladder cancer by age $a$ given that this age occurs in year $y$, baseline exposure $z_{a,y}$ and option exposure $x_{a,y}$ |
| $LR_{a,y}(x_{a,y})$ | Recursive estimate of the lifetime risk of bladder cancer within age interval [0, $a$) under the option conditions, given that age $a$ occurs in year $y$ |
| $NC_{A,y,s}$ | The incremental number of new stage $s$ bladder cancer cases in year $y$ for the model population aged $A$ in 2025. |
| $LC_{A,y,s}$ | The incremental number of individuals living with stage $s$ bladder cancer in year $y$ for the model population aged $A$ in 2025. |
| $ED_{A,y}$ | The incremental number of excess in stage $s$ bladder cancer population in year $y$ for the model population aged $A$ in 2025. |

### *Detailed Input Data*

As noted in Section 4, EPA relied on the federal government data sources including EPA SDWIS, ACS 2019 (U.S. Census Bureau, 2019), the Surveillance, Epidemiology, and End Results (SEER) program database (National Cancer Institute), and the Center for Disease Control (CDC) National Center for Health Statistics to characterize sex- and age group-specific general population mortality rates and bladder cancer incidence rates used in model simulations. All of these data are compiled by the relevant federal agencies and thus meet federal government data quality standards. These data sources are appropriate for this analysis based on the standards underlying their collection and publication, and their applicability to analyzing health effects of exposure to TTHM via drinking water. Table 4-6 in Section 4 summarizes the sex- and age group-specific share of general population mortality rates and bladder cancer incidence. Table C-2 below summarizes sex- and age group-specific distribution of bladder cancer cases over four analyzed stages as well as onset-specific relative survival probability for each stage.

**Table C-2: Summary of Baseline Bladder Cancer Incidence Data Used in the Model**

| Age | Females | | | | | Males | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Incidence per 100K | Percent of Incidence in Stage | | | | Incidence per 100K | Percent of Incidence in Stage | | | |
| | | Localized | Regional | Distant | Unstaged | | Localized | Regional | Distant | Unstaged |
| <1 | - | 77 | 4.5 | 14 | 4.5 | - | 66 | 23 | 11 | 0 |
| 1-4 | - | 77 | 4.5 | 14 | 4.5 | - | 66 | 23 | 11 | 0 |
| 5-9 | - | 77 | 4.5 | 14 | 4.5 | - | 66 | 23 | 11 | 0 |
| 10-14 | - | 77 | 4.5 | 14 | 4.5 | - | 66 | 23 | 11 | 0 |
| 15-19 | - | 82 | 8.2 | 5.1 | 4.9 | 0.11 | 90 | 4.8 | 3.1 | 2.5 |
| 20-24 | 0.17 | 82 | 8.2 | 5.1 | 4.9 | 0.3 | 90 | 4.8 | 3.1 | 2.5 |
| 25-29 | 0.26 | 82 | 8.2 | 5.1 | 4.9 | 0.51 | 90 | 4.8 | 3.1 | 2.5 |
| 30-34 | 0.5 | 82 | 8.2 | 5.1 | 4.9 | 1.1 | 90 | 4.8 | 3.1 | 2.5 |
| 35-39 | 0.89 | 82 | 8.2 | 5.1 | 4.9 | 2.1 | 90 | 4.8 | 3.1 | 2.5 |
| 40-44 | 1.5 | 83 | 8.6 | 6.1 | 2.7 | 4.2 | 85 | 7.4 | 4.9 | 2.5 |
| 45-49 | 2.9 | 83 | 8.6 | 6.1 | 2.7 | 8.8 | 85 | 7.4 | 4.9 | 2.5 |
| 50-54 | 6.6 | 83 | 8.6 | 6.1 | 2.7 | 19 | 85 | 7.4 | 4.9 | 2.5 |
| 55-59 | 11 | 83 | 8.6 | 6.1 | 2.7 | 38 | 85 | 7.4 | 4.9 | 2.5 |
| 60-64 | 18 | 83 | 8.6 | 6.1 | 2.7 | 67 | 85 | 7.4 | 4.9 | 2.5 |
| 65-69 | 29 | 84 | 7.9 | 5.6 | 2.8 | 114 | 86 | 6.7 | 4.3 | 2.9 |
| 70-74 | 43 | 84 | 7.9 | 5.6 | 2.8 | 176 | 86 | 6.7 | 4.3 | 2.9 |
| 75-79 | 58 | 80 | 7.1 | 5.8 | 6.8 | 245 | 85 | 6.2 | 4.1 | 5.2 |
| 80-84 | 71 | 80 | 7.1 | 5.8 | 6.8 | 315 | 85 | 6.2 | 4.1 | 5.2 |
| 85+ | 76 | 80 | 7.1 | 5.8 | 6.8 | 357 | 85 | 6.2 | 4.1 | 5.2 |

**Table C-3: Summary of Relative and Absolute Bladder Cancer Survival Used in the Model**

| Age at Diagnosis | Follow-Up Time | Females | | | | | | | | Males | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Relative Survival by Stage (Percent) | | | | Absolute Survival (Average) by Stage (Percent) | | | | Relative Survival by Stage (Percent) | | | | Absolute Survival (Average) by Stage (Percent) | | | |
| | | Localized | Regional | Distant | Unstaged | Localized | Regional | Distant | Unstaged | Localized | Regional | Distant | Unstaged | Localized | Regional | Distant | Unstaged |
| Ages 15-39 | 1 year | 98 | 79 | 20 | 90 | 97 | 79 | 20 | 90 | 99 | 85 | 46 | 100 | 97 | 83 | 45 | 98 |
| Ages 15-39 | 2 years | 97 | 58 | 4 | 83 | 96 | 57 | 4 | 83 | 99 | 67 | 23 | 97 | 96 | 65 | 22 | 95 |
| Ages 15-39 | 3 years | 96 | 47 | 0 | 80 | 95 | 46 | 0 | 79 | 98 | 60 | 14 | 95 | 96 | 58 | 13 | 92 |
| Ages 15-39 | 4 years | 95 | 39 | 0 | 80 | 94 | 39 | 0 | 79 | 97 | 58 | 11 | 91 | 95 | 56 | 11 | 89 |
| Ages 15-39 | 5 years | 95 | 32 | 0 | 80 | 93 | 32 | 0 | 79 | 96 | 56 | 11 | 91 | 94 | 54 | 11 | 89 |
| Ages 15-39 | 6 years | 94 | 28 | 0 | 80 | 93 | 27 | 0 | 79 | 96 | 56 | 9 | 91 | 93 | 54 | 9 | 89 |
| Ages 15-39 | 7 years | 94 | 28 | 0 | 80 | 92 | 27 | 0 | 79 | 96 | 56 | 7 | 91 | 93 | 54 | 7 | 88 |
| Ages 15-39 | 8 years | 93 | 28 | 0 | 80 | 92 | 27 | 0 | 78 | 95 | 56 | 7 | 91 | 92 | 54 | 7 | 88 |
| Ages 15-39 | 9 years | 93 | 28 | 0 | 80 | 91 | 27 | 0 | 78 | 94 | 52 | 5 | 91 | 91 | 51 | 4 | 88 |
| Ages 15-39 | 10 years | 93 | 28 | 0 | 80 | 91 | 27 | 0 | 78 | 93 | 52 | 5 | 85 | 90 | 50 | 4 | 82 |
| Ages 40-64 | 1 year | 97 | 73 | 34 | 84 | 92 | 69 | 32 | 80 | 98 | 78 | 36 | 85 | 90 | 72 | 33 | 78 |
| Ages 40-64 | 2 years | 95 | 53 | 15 | 81 | 90 | 50 | 14 | 76 | 96 | 57 | 16 | 79 | 87 | 52 | 15 | 72 |
| Ages 40-64 | 3 years | 94 | 45 | 9 | 77 | 88 | 42 | 9 | 72 | 94 | 48 | 11 | 75 | 85 | 43 | 10 | 67 |
| Ages 40-64 | 4 years | 93 | 40 | 7 | 76 | 87 | 37 | 7 | 70 | 93 | 43 | 9 | 73 | 83 | 38 | 8 | 65 |
| Ages 40-64 | 5 years | 92 | 37 | 5 | 74 | 85 | 34 | 5 | 69 | 91 | 40 | 8 | 71 | 81 | 35 | 7 | 63 |
| Ages 40-64 | 6 years | 91 | 36 | 5 | 74 | 84 | 33 | 5 | 68 | 90 | 38 | 7 | 68 | 79 | 33 | 7 | 60 |
| Ages 40-64 | 7 years | 90 | 34 | 4 | 73 | 82 | 31 | 4 | 66 | 89 | 37 | 7 | 66 | 77 | 32 | 6 | 57 |
| Ages 40-64 | 8 years | 89 | 32 | 4 | 71 | 80 | 29 | 4 | 64 | 88 | 36 | 7 | 64 | 75 | 30 | 6 | 54 |
| Ages 40-64 | 9 years | 88 | 31 | 4 | 70 | 79 | 28 | 3 | 63 | 87 | 35 | 7 | 61 | 73 | 29 | 6 | 51 |
| Ages 40-64 | 10 years | 87 | 31 | 4 | 70 | 77 | 27 | 3 | 62 | 86 | 34 | 7 | 61 | 71 | 28 | 6 | 51 |
| Ages 65-74 | 1 year | 95 | 67 | 25 | 72 | 88 | 62 | 24 | 66 | 97 | 74 | 32 | 81 | 86 | 66 | 29 | 72 |
| Ages 65-74 | 2 years | 92 | 48 | 11 | 67 | 83 | 44 | 10 | 61 | 94 | 55 | 16 | 75 | 82 | 48 | 13 | 65 |
| Ages 65-74 | 3 years | 90 | 38 | 8 | 63 | 80 | 34 | 7 | 57 | 92 | 47 | 11 | 72 | 77 | 39 | 9 | 60 |
| Ages 65-74 | 4 years | 88 | 34 | 6 | 60 | 77 | 30 | 5 | 52 | 89 | 42 | 8 | 69 | 73 | 34 | 6 | 56 |
| Ages 65-74 | 5 years | 86 | 31 | 5 | 58 | 73 | 26 | 5 | 50 | 88 | 39 | 6 | 66 | 70 | 31 | 5 | 52 |

**Table C-3: Summary of Relative and Absolute Bladder Cancer Survival Used in the Model**

| | | Females | | | | | | | | Males | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Relative Survival by Stage (Percent) | | | | Absolute Survival (Average) by Stage (Percent) | | | | Relative Survival by Stage (Percent) | | | | Absolute Survival (Average) by Stage (Percent) | | | |
| Age at Diagnosis | Follow-Up Time | Localized | Regional | Distant | Unstaged | Localized | Regional | Distant | Unstaged | Localized | Regional | Distant | Unstaged | Localized | Regional | Distant | Unstaged |
| Ages 65-74 | 6 years | 85 | 28 | 5 | 56 | 71 | 23 | 4 | 47 | 86 | 36 | 6 | 64 | 66 | 27 | 4 | 49 |
| Ages 65-74 | 7 years | 84 | 27 | 4 | 54 | 68 | 22 | 3 | 44 | 84 | 34 | 5 | 61 | 62 | 25 | 4 | 45 |
| Ages 65-74 | 8 years | 82 | 25 | 4 | 52 | 64 | 20 | 3 | 41 | 82 | 32 | 5 | 57 | 58 | 23 | 4 | 40 |
| Ages 65-74 | 9 years | 81 | 25 | 3 | 51 | 61 | 19 | 2 | 39 | 80 | 30 | 4 | 56 | 54 | 20 | 3 | 38 |
| Ages 65-74 | 10 years | 79 | 25 | 3 | 51 | 58 | 18 | 2 | 37 | 79 | 29 | 4 | 56 | 50 | 19 | 3 | 36 |
| Ages 75+ | 1 year | 86 | 48 | 17 | 39 | 44 | 25 | 9 | 20 | 92 | 60 | 22 | 59 | 45 | 30 | 11 | 29 |
| Ages 75+ | 2 years | 81 | 36 | 8 | 32 | 40 | 18 | 4 | 16 | 87 | 44 | 10 | 51 | 42 | 21 | 5 | 24 |
| Ages 75+ | 3 years | 77 | 30 | 6 | 27 | 38 | 15 | 3 | 13 | 84 | 38 | 7 | 45 | 38 | 17 | 3 | 21 |
| Ages 75+ | 4 years | 76 | 28 | 5 | 24 | 36 | 13 | 2 | 11 | 81 | 35 | 5 | 40 | 35 | 15 | 2 | 17 |
| Ages 75+ | 5 years | 73 | 26 | 4 | 22 | 33 | 12 | 2 | 10 | 79 | 33 | 5 | 37 | 33 | 14 | 2 | 15 |
| Ages 75+ | 6 years | 71 | 24 | 4 | 22 | 31 | 11 | 2 | 9 | 76 | 32 | 4 | 34 | 30 | 13 | 2 | 13 |
| Ages 75+ | 7 years | 69 | 22 | 3 | 20 | 29 | 9 | 1 | 8 | 74 | 29 | 3 | 31 | 27 | 11 | 1 | 11 |
| Ages 75+ | 8 years | 68 | 21 | 3 | 18 | 27 | 8 | 1 | 7 | 72 | 28 | 3 | 29 | 25 | 10 | 1 | 10 |
| Ages 75+ | 9 years | 66 | 21 | 2 | 18 | 25 | 8 | 1 | 7 | 70 | 28 | 3 | 26 | 22 | 9 | 1 | 8 |
| Ages 75+ | 10 years | 65 | 18 | 2 | 18 | 23 | 6 | 1 | 6 | 68 | 28 | 3 | 23 | 20 | 8 | 1 | 7 |

**Table C-4: Summary of All-Cause and Bladder Cancer Mortality Data Used in the Model**

| Age | Females | | | Males | | |
|---|---|---|---|---|---|---|
| | Rate per 100K | | Percent Bladder Cancer | Rate per 100K | | Percent Bladder Cancer |
| | All-Cause | Bladder Cancer | | All-Cause | Bladder Cancer | |
| <1 | 537 | - | - | 646 | 0.01 | 0.00 |
| 1-4 | 36 | - | - | 44 | - | - |
| 5-9 | 12 | - | - | 15 | - | - |
| 10-14 | 10 | - | - | 12 | 0.01 | 0.07 |
| 15-19 | 19 | - | - | 34 | - | - |
| 20-24 | 40 | 0.01 | 0.02 | 112 | 0.01 | 0.01 |
| 25-29 | 54 | 0.02 | 0.03 | 142 | 0.02 | 0.01 |
| 30-34 | 73 | 0.03 | 0.05 | 159 | 0.05 | 0.03 |
| 35-39 | 98 | 0.14 | 0.14 | 185 | 0.19 | 0.10 |
| 40-44 | 135 | 0.31 | 0.23 | 229 | 0.52 | 0.23 |
| 45-49 | 203 | 0.64 | 0.31 | 323 | 1.40 | 0.42 |
| 50-54 | 317 | 1.30 | 0.40 | 508 | 3.10 | 0.61 |
| 55-59 | 470 | 2.20 | 0.48 | 784 | 7.10 | 0.91 |
| 60-64 | 675 | 4.00 | 0.60 | 1,136 | 12.00 | 1.10 |
| 65-69 | 987 | 6.50 | 0.66 | 1,593 | 22.00 | 1.40 |
| 70-74 | 1,533 | 12.00 | 0.77 | 2,304 | 37.00 | 1.60 |
| 75-79 | 2,481 | 22.00 | 0.87 | 3,577 | 70.00 | 1.90 |
| 80-84 | 4,171 | 36.00 | 0.85 | 5,770 | 123.00 | 2.10 |
| 85+ | - | - | 0.77 | - | - | 1.90 |

## C.2 Detailed Results from Analysis

The health impact model assumes that the proposed regulatory changes begin in 2025 and end by 2049 and thus TTHM changes are in effect during this period. After 2049, TTHM levels return to baseline levels, *i.e.*, ΔTTHM is zero. Due to the lasting effects of changes in TTHM exposure, the benefits of the policies after 2049 were included in the final calculations for each option. Table C-5 summarizes the health impact and valuation results in millions of 2021 dollars for each proposed regulatory option, as shown graphically and discussed in Section 4.4.

**Table C-5: Number of Adverse Health Effects Avoided Over Time Starting from 2025**

| Option | Evaluation period | | | | | | | | | | | Total[d] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2025-2029 | 2030-2039 | 2040-2049 | 2050-2059 | 2060-2069 | 2070-2079 | 2080-2089 | 2090-2099 | 2100-2109 | 2110-2119 | 2120-2125 | |
| | **Cancer morbidity cases avoided[a,c]** | | | | | | | | | | | |
| Option 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 5 |
| Option 2 | 2 | 20 | 29 | 13 | 13 | 12 | 11 | 7 | 2 | 0 | 0 | 110 |
| Option 3 | 2 | 21 | 30 | 14 | 13 | 13 | 11 | 7 | 3 | 0 | 0 | 112 |
| Option 4 | 3 | 27 | 39 | 19 | 18 | 17 | 15 | 10 | 3 | -1 | 0 | 149 |
| | **Excess cancer deaths avoided[b,c]** | | | | | | | | | | | |
| Option 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 |
| Option 2 | 0 | 4 | 7 | 4 | 4 | 4 | 3 | 3 | 1 | 0 | 0 | 31 |
| Option 3 | 0 | 5 | 8 | 5 | 4 | 4 | 3 | 3 | 1 | 0 | 0 | 32 |
| Option 4 | 1 | 6 | 10 | 6 | 5 | 5 | 4 | 3 | 2 | 0 | 0 | 42 |
| | **Annual value of morbidity avoided (million dollars)[c]** | | | | | | | | | | | |
| Option 1 | $0.00 | $0.02 | $0.02 | $0.01 | $0.01 | $0.01 | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 | $0.07 |
| Option 2 | $0.03 | $0.34 | $0.42 | $0.20 | $0.14 | $0.10 | $0.07 | $0.04 | $0.01 | $0.00 | $0.00 | $1.35 |
| Option 3 | $0.04 | $0.35 | $0.43 | $0.20 | $0.14 | $0.10 | $0.07 | $0.04 | $0.01 | $0.00 | $0.00 | $1.38 |
| Option 4 | $0.07 | $0.45 | $0.55 | $0.27 | $0.20 | $0.14 | $0.09 | $0.05 | $0.02 | $0.00 | $0.00 | $1.83 |
| | **Annual value of mortality avoided (million dollars)[c]** | | | | | | | | | | | |
| Option 1 | $0.12 | $1.80 | $2.60 | $1.33 | $0.84 | $0.61 | $0.40 | $0.22 | $0.08 | $0.00 | $0.00 | $8.01 |
| Option 2 | $3.64 | $41.61 | $54.45 | $25.82 | $15.91 | $11.42 | $7.67 | $4.49 | $1.61 | $0.08 | -$0.02 | $166.68 |
| Option 3 | $3.84 | $42.57 | $55.70 | $26.51 | $16.37 | $11.75 | $7.88 | $4.60 | $1.65 | $0.08 | -$0.02 | $170.93 |
| Option 4 | $6.91 | $54.90 | $71.48 | $35.36 | $22.28 | $15.92 | $10.67 | $6.20 | $2.22 | $0.11 | -$0.03 | $226.01 |

Notes:

a. Number of TTHM-attributable bladder cancer cases that are expected to be avoided under the policy in the calendar time period.

b. Number of excess deaths among the TTHM-attributable bladder cancer cases that are expected to be avoided under the policy in the calendar time period.

c. Number of attributable cases and deaths are rounded to the nearest digit. Values of avoided morbidity and mortality are rounded to the nearest cent. Negative values represent increases in the number of cases/deaths and morbidity/mortality costs.

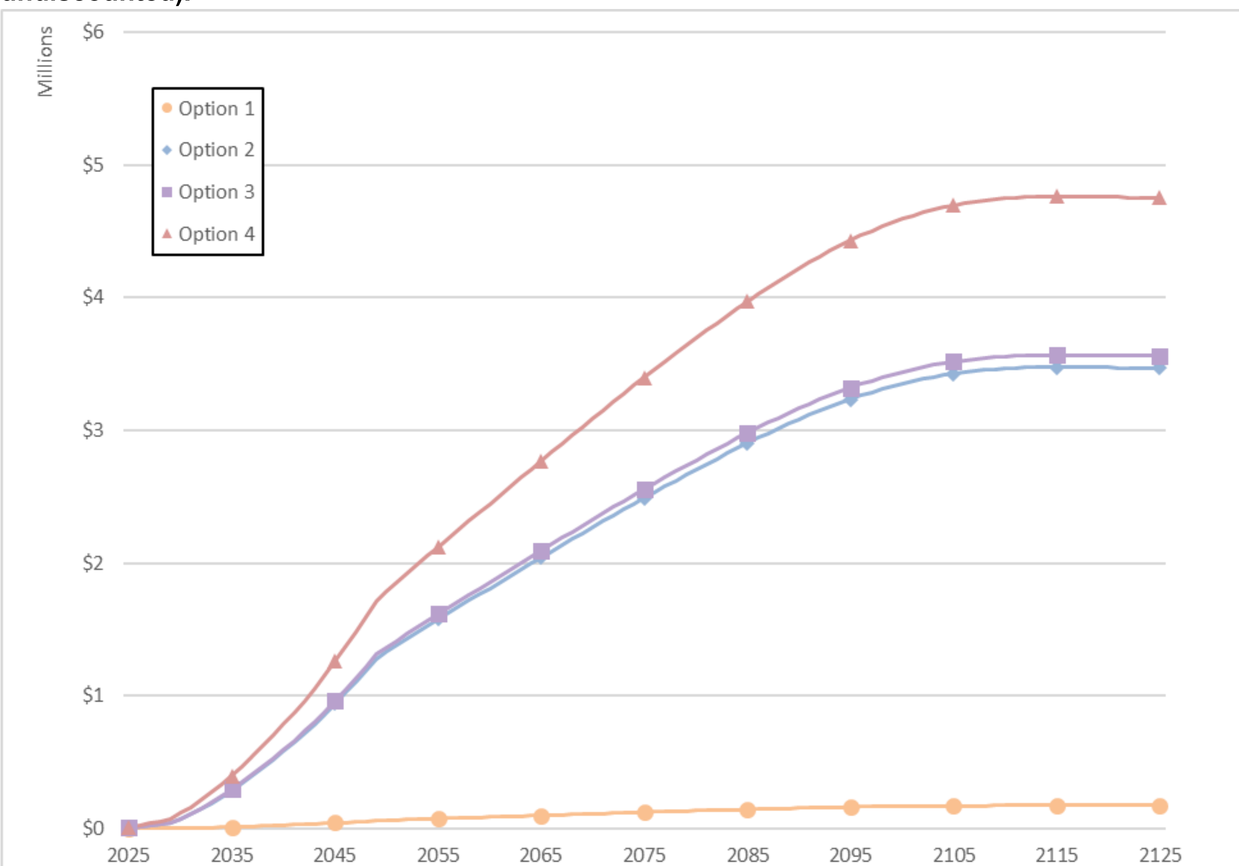
d. Total TTHM-attributable adverse health effects that are expected to be avoided between 2025 and 2125 as a result of the regulatory option changes in 2025-2049.

*Source: U.S. EPA Analysis, 2022*

### C.3 Temporal Distribution of Benefits

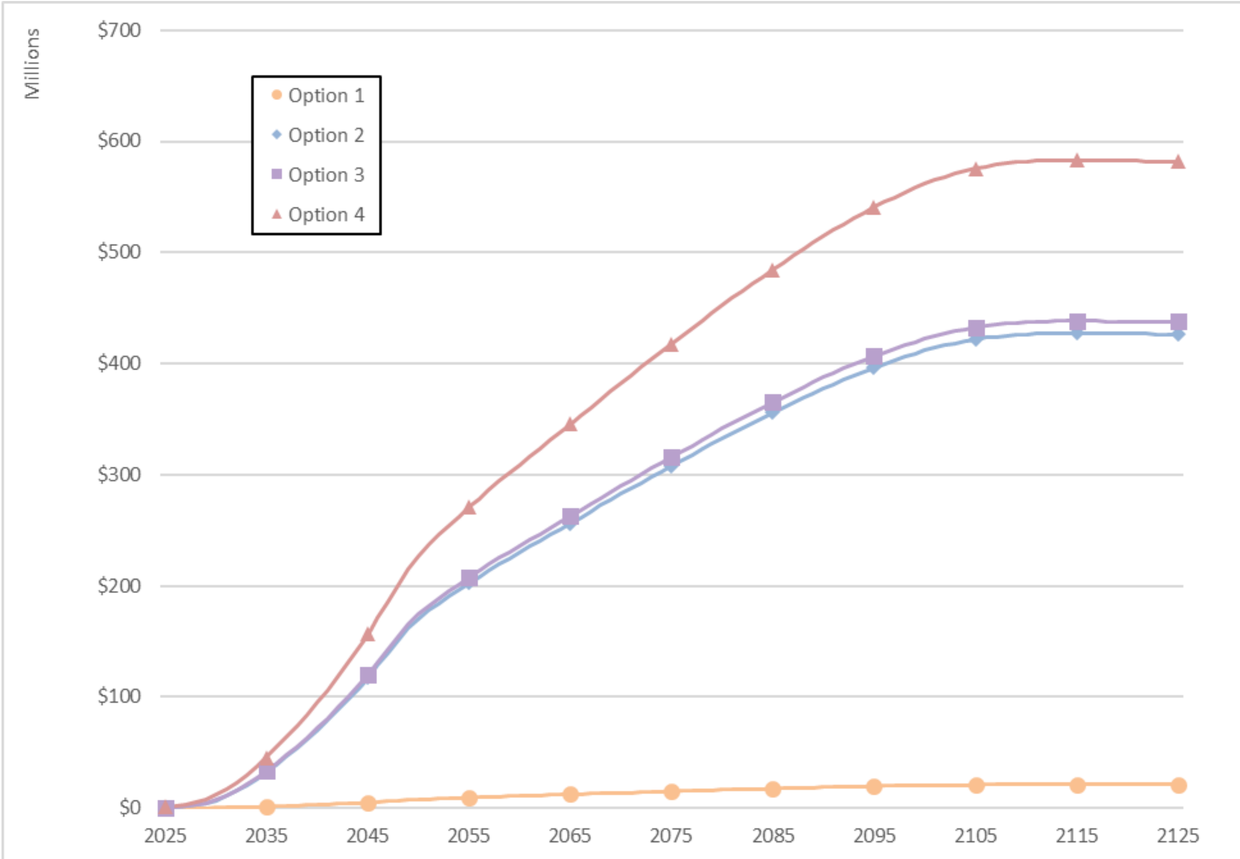
Figure C-2 and Figure C-3 illustrate patterns of changes in benefits for the four regulatory options for the 100-year simulation period of 2025 through 2125 based on the cumulative annual value of morbidity avoided and the cumulative annual value of mortality, respectively (values are undiscounted). These figures show the gradual increase in benefits for Options 2, 3, and 4 between 2025 and 2049, which continues but at a reduced rate after 2049 until levelling off around 2107. As discussed in Section 4.4, benefits decrease during the final decade for Options 2, 3, and 4. The magnitude of benefits associated with Option 1 are much smaller than those of Options 2, 3, and 4.

**Figure C-2: Cumulative Annual Value of Cancer Morbidity Avoided, 2025-2125 (Million 2021$ undiscounted).**




*Source: U.S. EPA Analysis, 2022.*

**Figure C-3. Cumulative Annual Value of Mortality Avoided, 2025-2125 (Million 2021$ undiscounted).**




*Source: U.S. EPA Analysis, 2022.*

# Appendix D Derivation of Ambient Water and Fish Tissue Concentrations in 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 EA and TDD for the regulatory options (U.S. EPA, 2023a, 2023d). The following sections discuss calculations of the toxics concentrations in ambient water and fish tissue and nutrient and sediment concentrations in ambient water.

## D.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.[119] The hydrography network represented in the D-FATE model consists of 11,515 reaches within 300 km of a steam electric power plant, 9.3258 of which are estimated to be potentially fishable.[120]

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, 2023a.

- **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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119 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.

120 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.

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.[121]

- **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 2019. 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 EA for estimating fish tissue concentrations for receiving reaches (U.S. EPA, 2023a), 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 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 EA, U.S. EPA, 2023a) 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.

The analysis provides background toxic-specific composite fish fillet concentrations for each reach modeled in the D-FATE model (Table D-1). Total fish tissue concentrations (D-FATE modeled concentrations plus background concentrations) are summarized in Table D-2.

**Table D-1: Background Fish Tissue Concentrations, based on 10$^{th}$ percentile**

| Parameter | Pollutant Concentration (mg/kg) |
|---|---|
| As | 0.039 |
| Hg | 0.058 |
| Pb | 0.039 |

*Source: U.S. EPA Analysis, 2022*

121 For some analyses, EPA limits the scope of reaches to 300 km (186 miles) downstream from steam electric power plant outfalls.

**Table D-2: 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 | 0.039 | 0.143 | 0.039 | 0.039 | 0.284 | 0.039 | 0.058 | 9.754 | 0.088 |
| Option 1 | 0.039 | 0.090 | 0.039 | 0.039 | 0.284 | 0.039 | 0.058 | 7.044 | 0.075 |
| Option 2 | 0.039 | 0.090 | 0.039 | 0.039 | 0.284 | 0.039 | 0.058 | 7.044 | 0.075 |
| Option 3 | 0.039 | 0.090 | 0.039 | 0.039 | 0.186 | 0.039 | 0.058 | 7.044 | 0.075 |
| Option 4 | 0.039 | 0.090 | 0.039 | 0.039 | 0.186 | 0.039 | 0.058 | 7.044 | 0.075 |
| **Period 2** | | | | | | | | | |
| Baseline | 0.039 | 0.143 | 0.039 | 0.039 | 0.092 | 0.039 | 0.058 | 9.754 | 0.086 |
| Option 1 | 0.039 | 0.055 | 0.039 | 0.039 | 0.092 | 0.039 | 0.058 | 1.768 | 0.062 |
| Option 2 | 0.039 | 0.055 | 0.039 | 0.039 | 0.064 | 0.039 | 0.058 | 1.325 | 0.062 |
| Option 3 | 0.039 | 0.055 | 0.039 | 0.039 | 0.040 | 0.039 | 0.058 | 1.325 | 0.062 |
| Option 4 | 0.039 | 0.055 | 0.039 | 0.039 | 0.040 | 0.039 | 0.058 | 1.325 | 0.062 |

*Source: U.S. EPA Analysis, 2022.*

## D.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 (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[122] 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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[122] TSS loadings are converted to SSC values at this step by using location-specific relationships built into the SPARROW regional models.

# Appendix E Georeferencing Surface Water Intakes to the Medium-resolution Reach Network

For the 2022 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 downstream flowpath via NHD Plus Version 2 Flowlines for all steam electric dischargers.
2. Identify intakes within a 5-kilometer buffer of the downstream flowpath. This distance is used to limit the set of points to be visually reviewed in the next step and provides an upper bound of the distance between an intake and its potential associated receiving water.
3. Visually review the location of each intake within the five-kilometer buffer to determine whether the intake is on a waterbody downstream of steam electric power plant discharges. The visual assessment accounts for hydrographic connectivity and flow direction.

EPA then paired the intakes that were confirmed to be impacted to the closest NHD COMID based on a simple cartesian distance.

# Appendix 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, 2019c). 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 (2021$) based on Expected Reductions in Lifetime Earnings**

| Discount Rate | Value of an IQ Point[a] (2021$) |
|---|---|
| | Value of an IQ point Discounted to Age 3 |
| 3 percent | $12,118 |
| 7 percent | $2,548 |
| | Value of an IQ point Discounted to Birth |
| 3 percent | $11,089 |
| 7 percent | $2,080 |

a. Values are adjusted for the cost of education.

*Source: U.S. EPA, 2019c and 2019d analysis of data from Lin et al. (2018)*

## F.1 Health Effects in Children from Changes in Lead Exposure

Table F-2 shows the benefits associated with avoided IQ losses from lead exposure via fish consumption. The total net change in avoided IQ point losses over the entire population of children with reductions in lead exposure ranges from 1 point to 6 points. Annualized benefits of avoided IQ losses from reductions in lead exposure, based on the Lin *et al.* (2018) IQ point value, range from approximately $300 to $2,800 (3 percent discount rate) and from approximately $100 to $600 (7 percent discount rate).

**Table F-2: Estimated Benefits of Avoided 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 Avoided IQ Point Losses, 2025 to 2049, in All Children 0 to 7 in Scope of the Analysis | Annualized Value of Changes in IQ Point Losses[a] (Thousands of 2021$) | |
|---|---|---|---|---|
| | | | 3 Percent Discount Rate | 7 Percent Discount Rate |
| Option 1 | 1,427,107 | 1 | $0.3 | $0.1 |
| Option 2 | 1,427,107 | 2 | $0.8 | $0.2 |
| Option 3 | 1,427,107 | 6 | $2.8 | $0.6 |
| Option 4 | 1,427,107 | 6 | $2.8 | $0.6 |

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, 2019c).

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, 2022*

## F.2 Heath Effects in Children from Changes in Mercury Exposure

Table F-3 shows the estimated changes in avoided IQ point losses for infants exposed to mercury in-utero and the corresponding monetary benefits, using 3 percent and 7 percent discount rates. The total net change in avoided IQ point losses over the entire population of infants with reductions in mercury exposure ranges from 3,712 points (Option 1) to 3,923 points (Option 4). Annualized benefits of avoided IQ losses from reductions in mercury exposure, based on the Lin *et al.* (2018) IQ point value, range from $0.3 million (7 percent discount rate) to $1.7 million (3 percent discount rate).

**Table F-3: Estimated Benefits of Avoided IQ Losses for Infants from Mercury Exposure under the Regulatory Options, Compared to Baseline**

| Regulatory Option | Average Annual Number of Infants in Scope of the Analysis[b] | Total Avoided IQ Point Losses, 2025 to 2049, in All Infants in Scope of the Analysis | Annualized Value of Changes in IQ Point Losses[a] (Millions 2021$) | |
|---|---|---|---|---|
| | | | 3 Percent Discount Rate | 7 Percent Discount Rate |
| Option 1 | 187,496 | 3,712 | $1.59 | $0.28 |
| Option 2 | 187,496 | 3,776 | $1.62 | $0.29 |
| Option 3 | 187,496 | 3,920 | $1.68 | $0.30 |
| Option 4 | 187,496 | 3,923 | $1.69 | $0.30 |

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, 2019c and 2019d).

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, 2022*

# Appendix 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). To update results of the 2015 meta-analysis, EPA first conducted a literature review and identified 10 new studies to augment the existing meta-data. EPA also performed quality assurance on the meta-data, identifying revisions that improved accuracy and consistency within the meta-data, and added or removed observations from existing studies, as appropriate. EPA then re-estimated the MRM and made additional improvements to the model by introducing explanatory variables to account for different survey methodologies, WTP estimation methodologies, payment mechanisms, and water quality metrics used in some of the added studies. A memorandum titled "Revisions to the Water Quality Meta-Data and Meta-Regression Models after the 2020 Steam Electric Analysis through December 2021" (ICF, 2022) details changes to the meta-data and MRMs following the 2020 Steam Electric ELG analysis (U.S. EPA, 2020e), summarizes how the studies and observations included in the meta-data have changed from 2015 to 2020 to present, and compares the latest MRM results with those from 2015 (U.S. EPA, 2015a) and 2020 (U.S. EPA, 2020e).

Table G-1 summarizes studies in the revised meta-data, including number of observations from each study, state-level study location, waterbody type, geographic scope, and household WTP summary statistics. In total, the revised meta-data includes 189 observations from 59 stated preference studies that estimated per household WTP (use plus nonuse) for water quality changes in U.S. waterbodies. The studies address various waterbody types including, rivers, lakes, salt ponds/marshes, and estuaries. The ten studies added to the meta-data since 2015 are shaded in Table G-1.

**Table G-1. Primary Studies Included in the Meta-data**

| Study | Obs. In Meta-data | State(s) | Waterbody Type(s) | Geographic Scope | WTP Per Household (2019$) | | |
|---|---|---|---|---|---|---|---|
| | | | | | Mean | Min | Max |
| Aiken (1985) | 1 | CO | river/ stream and lake | Entire state | $238.19 | $238.19 | $238.19 |
| Anderson and Edwards (1986) | 1 | RI | salt pond /marsh | Coastal salt ponds (South Kingstown, Charlestown, and Narragansett) | $222.82 | $222.82 | $222.82 |
| Banzhaf *et al.* (2006) | 2 | NY | lake | Adirondack Park, New York State | $70.86 | $66.69 | $75.03 |
| Banzhaf *et al.* (2016) | 1 | VA, WV, TN, NC, GA | river/ stream | Southern Appalachian Mountains region | $18.67 | $18.67 | $18.67 |
| Bockstael *et al.* (1989) | 2 | MD, DC, VA | estuary | Chesapeake Bay (Baltimore-Washington Metropolitan Area) | $137.31 | $93.30 | $181.32 |
| Borisova *et al.* (2008) | 2 | VA/WV | river/ stream | Opequon Creek watershed | $42.54 | $22.25 | $62.83 |
| Cameron and Huppert (1989) | 1 | CA | estuary | San Francisco Bay | $61.07 | $61.07 | $61.07 |
| Carson *et al.* (1994) | 2 | CA | estuary | Southern California Bight | $73.24 | $50.81 | $95.67 |

| Table G-1. Primary Studies Included in the Meta-data | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Study** | **Obs. In Meta-data** | **State(s)** | **Waterbody Type(s)** | **Geographic Scope** | **WTP Per Household (2019$)** | | |
| | | | | | **Mean** | **Min** | **Max** |
| Choi and Ready (2019) | 6 | PA | river/ stream | Three creek watersheds: Spring, Mahantango, and Conewago | $4.56 | $1.73 | $10.40 |
| Clonts and Malone (1990) | 2 | AL | river/ stream | 15 free-flowing rivers, AL | $112.28 | $96.56 | $128.00 |
| Collins and Rosenberger (2007) | 1 | WV | river/ stream | Cheat River Watershed | $22.43 | $22.43 | $22.43 |
| Collins *et al.* (2009) | 1 | WV | river/ stream | Deckers Creek Watershed | $229.82 | $229.82 | $229.82 |
| Corrigan (2008) | 1 | IA | lake | Clear Lake | $152.03 | $152.03 | $152.03 |
| Croke *et al.* (1986-1987) | 6 | IL | river/ stream | Chicago metropolitan area river system | $90.25 | $75.60 | $107.18 |
| De Zoysa (1995) | 1 | OH | river/ stream | Maumee River Basin | $86.53 | $86.53 | $86.53 |
| Desvousges *et al.* (1987) | 12 | PA | river/ stream | Monongahela River basin (PA portion) | $72.98 | $24.46 | $169.24 |
| Downstream Strategies LLC (2008) | 2 | PA | river/ stream | West Branch Susquehanna River watershed | $15.70 | $13.19 | $18.21 |
| Farber and Griner (2000) | 6 | PA | river/ stream | Loyalhanna Creek and Conemaugh River basins (western PA) | $93.91 | $20.45 | $183.21 |
| Hayes *et al.* (1992) | 2 | RI | estuary | Upper Narragansett Bay | $490.05 | $481.71 | $498.38 |
| Herriges and Shogren (1996) | 1 | IA | lake | Storm Lake watershed | $76.09 | $76.09 | $76.09 |
| Hite (2002) | 2 | MS | river/ stream | Entire state | $74.09 | $71.81 | $76.36 |
| Holland and Johnston (2017) | 6 | ME | river/ stream | Merriland, Branch Brook and Little River Watershed | $13.90 | $8.16 | $21.27 |
| Huang *et al.* (1997) | 2 | NC | estuary | Albemarle and Pamlico Sounds | $318.92 | $314.43 | $323.40 |
| Interis and Petrolia (2016) | 10 | AL/LA | estuary | Mobile Bay, AL; Barataria-Terrebonne estuary, LA | $87.91 | $45.00 | $140.47 |
| Irvin *et al.* (2007) | 4 | OH | river/ stream and lake | Entire state | $26.72 | $24.22 | $28.64 |
| Johnston and Ramachandran (2014) | 3 | RI | river/ stream | Pawtuxet watershed | $14.11 | $7.05 | $21.16 |
| Johnston *et al.* (2002) | 1 | RI | river/ stream | Wood-Pawcatuck watershed | $48.08 | $48.08 | $48.08 |
| R. J. Johnston et al. (2017) | 3 | RI | river/ stream | Pawtuxet watershed | $4.79 | $2.40 | $7.19 |
| Kaoru (1993) | 1 | MA | salt pond /marsh | Martha's Vineyard | $269.56 | $269.56 | $269.56 |

**Table G-1. Primary Studies Included in the Meta-data**

| Study | Obs. In Meta-data | State(s) | Waterbody Type(s) | Geographic Scope | WTP Per Household (2019$) | | |
|---|---|---|---|---|---|---|---|
| | | | | | Mean | Min | Max |
| Lant and Roberts (1990) | 3 | IA/IL | river/ stream | Des Moines, Skunk, English, Cedar, Wapsipinicon, Turkey; Illinois: Rock, Edwards, La Moine, Sangamon, Iroquois, and Vermillion River basins | $177.47 | $152.94 | $190.26 |
| Lant and Tobin (1989) | 9 | IA/IL | river/ stream | Edwards River, Wapsipinicon River, and South Skunk drainage basins | $68.59 | $50.04 | $83.40 |
| Lichtkoppler and Blaine (1999) | 1 | OH | river/ stream and lake | Ashtabula River and Ashtabula Harbor | $51.69 | $51.69 | $51.69 |
| Lindsey (1994) | 8 | MD | estuary | Chesapeake Bay | $82.37 | $41.18 | $126.02 |
| Lipton (2004) | 1 | MD | estuary | Chesapeake Bay Watershed | $78.88 | $78.88 | $78.88 |
| Londoño Cadavid and Ando (2013) | 2 | IL | river/ stream | Cities of Champaign and Urbana | $47.70 | $44.30 | $51.10 |
| Loomis (1996) | 1 | WA | river/ stream | Elwha River | $114.75 | $114.75 | $114.75 |
| Lyke (1993) | 2 | WI | river/ stream and lake | Wisconsin Great Lakes | $97.10 | $73.68 | $120.52 |
| Mathews *et al.* (1999) | 1 | MN | river/ stream | Minnesota River | $22.36 | $22.36 | $22.36 |
| C. Moore *et al.* (2018) | 2 | MD, VA, DC, DE, NY, PA, WV, CT, FL, GA, ME, MA, NH, NJ, NC, RI, SC, VT | lake | Chesapeake Bay Watershed | $131.21 | $77.75 | $184.67 |
| N. M. Nelson *et al.* (2015) | 2 | UT | river/ stream and lake | Entire state | $259.70 | $167.07 | $352.33 |
| Opaluch *et al.* (1998) | 1 | NY | estuary | Peconic Estuary System | $170.73 | $170.73 | $170.73 |
| Roberts and Leitch (1997) | 1 | MN/SD | lake | Mud Lake | $10.30 | $10.30 | $10.30 |
| Rowe *et al.* (1985) | 1 | CO | river/ stream | Eagle River | $165.95 | $165.95 | $165.95 |

**Table G-1. Primary Studies Included in the Meta-data**

| Study | Obs. In Meta-data | State(s) | Waterbody Type(s) | Geographic Scope | WTP Per Household (2019$) | | |
|---|---|---|---|---|---|---|---|
| | | | | | Mean | Min | Max |
| Sanders *et al.* (1990) | 4 | CO | river/ stream | Cache la Poudre, Colorado, Conejos, Dollores, Elk, Encampment, Green, Gunnison, Los Pinos, Piedra, and Yampa rivers | $198.13 | $99.89 | $258.99 |
| Schulze *et al.* (1995) | 4 | MT | river/ stream | Clark Fork River Basin | $75.19 | $56.62 | $95.54 |
| Shrestha and Alavalapati (2004) | 2 | FL | river/ stream and lake | Lake Okeechobee watershed | $192.92 | $170.12 | $215.72 |
| Stumborg *et al.* (2001) | 2 | WI | lake | Lake Mendota Watershed | $103.94 | $82.28 | $125.59 |
| Sutherland and Walsh (1985) | 1 | MT | river/ stream and lake | Flathead River drainage system | $180.05 | $180.05 | $180.05 |
| Takatsuka (2004) | 4 | TN | river/ stream | Clinch River watershed | $353.72 | $224.28 | $483.16 |
| Van Houtven *et al.* (2014) | 32 | VA, NC, SC, AL, GA, KY, MS, TN | lake | Entire state (separate observations for each state) | $316.16 | $260.91 | $374.11 |
| Wattage (1993) | 2 | IA | river/ stream | Bear Creek watershed | $53.68 | $49.61 | $57.76 |
| Welle (1986) | 4 | MN | lake | Entire state | $175.44 | $135.13 | $227.59 |
| Welle and Hodgson (2011) | 3 | MN | lake | Lake Margaret and Sauk River Chain of Lakes watersheds | $178.91 | $13.06 | $351.48 |
| Wey (1990) | 1 | RI | salt pond /marsh | Great Salt Pond (Block Island) | $78.85 | $78.85 | $78.85 |
| Whitehead (2006) | 3 | NC | river/ stream | Neuse River watershed | $230.79 | $33.93 | $450.72 |
| Whitehead and Groothuis (1992) | 2 | NC | river/ stream | Tar-Pamlico River | $43.08 | $39.33 | $46.82 |
| Whitehead *et al.* (1995) | 1 | NC | estuary | Albermarle-Pamlico estuary system | $115.56 | $115.56 | $115.56 |
| Whittington (1994) | 1 | TX | estuary | Galveston Bay estuary | $240.09 | $240.09 | $240.09 |
| Zhao *et al.* (2013) | 3 | RI | river/ stream and lake | Pawtuxet watershed | $7.19 | $3.59 | $10.78 |

*Source: U.S. EPA Analysis, 2022*

Similar to the 2015 MRM, the updated MRM satisfies the adding-up condition, a theoretically desirable property.[123] This condition ensures that if the model were used to estimate WTP for the cumulative water quality change resulting from several 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 (Moeltner, 2019; Newbold *et al.*, 2018).

The meta-analysis is based on 189 observations from 59 stated preference studies, published between 1985 and 2021. The variables in the meta-data fall into four general categories:

- *Study methodology and year variables* characterize such features as the year in which a study was conducted, payment vehicle and elicitation formats, 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.
- *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.
- *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.
- *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 the latest version of the MRM, EPA built upon published versions of the MRM (R. J. Johnston et al., 2017; Johnston *et al.*, 2019; U.S. Environmental Protection Agency, 2020b; U.S. Environmental Protection Agency, 2015a), with revisions to better account for methodological differences in the underlying studies (see ICF (2022) for detail on changes in the meta-data and the explanatory variables used in the regression equation).

EPA also revised regional indicators to match the U.S. Census regions (U.S. Census Bureau, n.d.). To correct for heteroskedasticity, the model is estimated using weighted least squares with observations weighted by sample size and robust standard errors (J. P. Nelson & Kennedy, 2009). Detailed discussion of this approach can be found in Vedogbeton and Johnston (2020). A comprehensive review of these methods is provided by Stanley (2005).

Table G-2 provides definitions and presents descriptive statistics for variables included in the MRM, based on the meta-data studies.

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123 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 ($Y_0$).

**Table G-2. Definition and Summary Statistics for Model Variables**

| Variable | Definition | Units | Mean | St. Dev. |
|---|---|---|---|---|
| **Dependent Variable** | | | | |
| *ln_OWTP* | Natural log of WTP per unit of water quality improvement, per household. | Natural log of 2019$ | 1.873 | 1.391 |
| *OWTP*[a] | WTP per unit of water quality improvement, per household. | 2019$ | 15.931 | 23.595 |
| **Study Methodology and Year** | | | | |
| *OneShotVal* | Binary variable indicating that the study's survey only included one valuation question. | Binary (Value: 0 or 1) | 0.534 | 0.500 |
| *tax_only*[b] | Binary variable indicating that the payment mechanism used to elicit WTP is increased taxes. | Binary (Value: 0 or 1) | 0.397 | 0.491 |
| *user_cost*[b] | Binary variable indicating that the payment mechanism used to elicit WTP is increased user costs. | Binary (Value: 0 or 1) | 0.021 | 0.144 |
| *RUM* | Binary variable indicating that the study used a Random Utility Model (RUM) to estimate WTP. | Binary (Value: 0 or 1) | 0.566 | 0.497 |
| *IBI* | Binary variable indicating that the study used the index of biotic integrity (IBI) as the water quality metric. | Binary (Value: 0 or 1) | 0.079 | 0.271 |
| *lnyear* | Natural log of the year in which the study was conducted (*i.e.*, data was collected), converted to an index by subtracting 1980. | Natural log of years (year ranges from 1981 to 2017). | 2.629 | 0.979 |
| *volunt*[b] | Binary variable indicating that WTP was estimated using a payment vehicle described as voluntary as opposed to, for example, property taxes. | Binary (Value: 0 or 1) | 0.058 | 0.235 |
| *non_reviewed* | Binary variable indicating that the study was not published in a peer-reviewed journal. | Binary (Value: 0 or 1) | 0.159 | 0.366 |
| *thesis* | Binary variable indicating that the study is a thesis. | Binary (Value: 0 or 1) | 0.079 | 0.271 |
| *lump_sum* | 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. This variable enables the benefit transfer analyst to estimate annual WTP values by setting *lump_sum*=0. | Binary (Value: 0 or 1) | 0.180 | 0.385 |
| **Region and Surveyed Populations** | | | | |
| *census_south*[c] | Binary variable indicating that the affected waters are located entirely within the South Census region, which includes the following states: DE, MD, DC, WV, VA, NC, SC, GA, FL, KY, TN, MS, AL, AR, LA, OK, and TX. | Binary (Value: 0 or 1) | 0.349 | 0.478 |
| *census_midwest*[c] | Binary variable indicating that the affected waters are located entirely within the Midwest Census region, which includes the following states: OH, MI, IN, IL, WI, MN, IA, MO, ND, SD, NE, and KS. | Binary (Value: 0 or 1) | 0.228 | 0.420 |
| *census_west*[c] | Binary variable indicating that the affected waters are located entirely within the West | Binary (Value: 0 or 1) | 0.090 | 0.287 |

**Table G-2. Definition and Summary Statistics for Model Variables**

| Variable | Definition | Units | Mean | St. Dev. |
|---|---|---|---|---|
| | Census region, which includes the following states: MT, WY, CO, NM, ID, UT, AZ, NV, WA, OR, and CA. | | | |
| *nonusers* | Binary variable indicating that the survey was implemented over a population of nonusers (default category for this variable is a survey of any population that includes both users and nonusers). | Binary (Value: 0 or 1) | 0.058 | 0.235 |
| *lnincome* | Natural log of the median income (in 2019$) for the sample area of each study based on historical U.S. Census data. It was designed to provide a consistent income variable given differences in reporting of respondent income across studies in the meta-data (*i.e.*, mean vs. median). Also, some studies do not report respondent income. This variable was estimated for all studies in the meta-data regardless of whether the study reported summary statistics for respondent income. | Natural log of income (2019$) | 10.946 | 0.160 |
| **Sampled Market and Affected Resource** | | | | |
| *swim_use* | Binary variable indicating that the affected use(s) stated in the study include swimming. | Binary (Value: 0 or 1) | 0.222 | 0.417 |
| *gamefish* | Binary variable indicating that the affected use stated in the study is game fishing. | Binary (Value: 0 or 1) | 0.190 | 0.394 |
| *ln_ar_agr*[d] | Natural log of the proportion of the affected resource area that is agricultural based on National Land Cover Database (NLCD), reflecting the nature of development in the area surrounding the resource. The affected resource area is defined as all counties that intersect the affected resource(s). | Natural log of proportion (Proportion Range: 0 to 1; $km^2/km^2$) | -1.648 | 0.912 |
| *ln_ar_ratio* | A ratio of the sampled area, in $km^2$, relative to the affected resource area. When not explicitly reported in the study, the affected resource area is measured as the total area of counties that intersect the affected resource(s), to create the variable *ar_total_area*. From here, *ln_ar_ratio* = log(*sa_area* / *ar_total_area*), where *sa_area* is the size of the sampled area in $km^2$. | Natural log of ratio ($km^2/km^2$) | -0.594 | 2.408 |
| *sub_proportion*[e] | The water bodies affected by the water quality change, as a proportion of all water bodies of the same hydrological type in the sampled area. The affected resource appears in both the numerator and denominator when calculating *sub_proportion*. The value can range from 0 to 1. | Proportion (Range: 0 to 1; km/km) | 0.351 | 0.401 |
| **Water Quality Baseline and Change** | | | | |
| *ln_Q* | Natural log of the mid-point of the baseline and policy water quality: Q = *(1/2)( WQI-BL + WQI-PC)*. | Natural log of WQI units | 3.944 | 0.295 |

**Table G-2. Definition and Summary Statistics for Model Variables**

| Variable | Definition | Units | Mean | St. Dev. |
|---|---|---|---|---|
| *lnquality_ch* | Natural log of the change in mean water quality (*quality_ch*), specified on the WQI. | Natural log of WQI units | 2.552 | 0.801 |

a. Provided for informational purposes. Model uses the natural log version of the *OWTP* variable as the dependent variable.

b. The payment types omitted from the payment type binary variables are: (1) increased prices, (2) increased prices and/or taxes, (3) multiple methods, (4) earmarked fund, and (5) not specified/unknown.

c. The regions omitted from the regional binary variables are the Northeast Census region (ME, NH, VT, MA, RI, CT, NY, PA, and NJ) and the Chesapeake Bay (studies focused on the Chesapeake Bay or Chesapeake Bay Watershed since the Chesapeake Bay Watershed spans two Census regions).

d. In addition to the *ln_ar_agr* variable, EPA tested a variable for the proportion of the affected resource area that is developed, but it did not improve model fit.

e. The *sub_proportion* estimation method differs by waterbody type. For rivers, the calculation is the length of the affected river reaches as a proportion of all reaches of the same order. For lakes and ponds, the calculation is the area of the affected waterbody as a proportion of all water bodies of the same National Hydrography Dataset classification. For bays and estuaries, the calculation is the shoreline length of the waterbody as a proportion of all analogous (*e.g.*, coastal) shoreline lengths. To account for observations where multiple waterbody types are affected, the variable *sub_proportion* is defined as the maximum of separate substitute proportions for rivers, lakes, and estuaries/bays.

*Source: U.S. EPA Analysis, 2022.*

Using the updated meta-data, EPA developed MRMs that predict how WTP for a one-point improvement on the WQI (hereafter, one-point WTP) depends on a variety of methodological, population, resource, and water quality change characteristics. The estimated MRMs predict the one-point 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 MRMs (U.S. EPA, 2015a). Model 1 is used to provide EPA's main 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 as a sensitivity analysis. 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:

- <u>Model 1</u> assumes that individuals' one-point 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.

- <u>Model 2</u> allows one-point 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 one-point 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 main estimate from Model 1.

EPA used the two MRMs in a benefit transfer approach that follows standard methods described by Johnston *et al.* (2005), Shrestha *et al.* (2007), and Rosenberger and Phipps (2007). Based on benefit transfer literature (*e.g.*, Stapler & Johnston, 2009; K.J. Boyle & Wooldridge, 2018), methodological variables are assigned values that either reflect "best practices" associated with reducing measurement errors in primary studies or set to their mean values over the meta-data. 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.[124] The transfer approach involved projecting benefits in each CBG and year, based on the following general benefit function:

**Equation G-1.**

$$\ln(OWTP_{Y,B}) = Intercept + \sum(coefficient_i) \times (independent\ variable\ value_i)$$

Where

| | | |
|---|---|---|
| $ln(OWTP_{Y,B})$ | = | The predicted natural log of one-point 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. |

Here, $ln(OWTP_{Y,B})$ is the dependent variable in the meta-analysis—the natural log of an average WTP per one point improvement per household, in a given CBG *B* for water quality in a given year *Y*.[125] 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 one-point WTP is assumed to depend, according to Equation G-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 one-point 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

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124 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.

125 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 WTP for a one-point improvement on the WQI.

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.[126] Total national WTP is calculated as the sum of estimated CBG-level WTP across all CBGs 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 in U.S. Environmental Protection Agency (2020b) 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-3 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 MRM 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.

In this instance, EPA assigned six study and methodology variables, (*thesis, volunt, non_reviewed, lump_sum, user_cost*, *IBI*) a value of zero. Three methodological variables (*OneShotVal*, *tax_only*, *RUM*) were included with an assigned value of 1. For the study year variable *(lnyear)*, EPA gave the variable a value of 3.6109 (or the ln(2017-1980)), which is the maximum value in the meta-data. This value assignment reflects a time trend interpretation of the variable. Model 2 includes an additional variable, water quality change (*ln_quality_ch*), which allows the benefit transfer function to reflect differences in one-point WTP based on the magnitude of changes presented to survey respondents when eliciting WTP values. To ensure that the benefit transfer function satisfies the adding-up condition, the *ln_quality_ch* 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 sensitivity analysis values of WTP for water quality changes resulting from the regulatory options, EPA estimated one-point WTP using two alternative settings of the *ln_quality_ch* variable: $\Delta$WQI = 7 units and $\Delta$WQI = 20 units. These two values represent the $25^{th}$ percentile and $75^{th}$ percentile values of 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 2019 American Community Survey (5-year data) and accounted for projected income growth over the analysis period using the methodology described in Section 1.3.6.

[126] Population double-counting issues can arise when using “distance to waterbody” to assess simultaneous improvements to many waterbodies.

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 9,358 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 9,358 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 COMIDs within the scope of the analysis and thus does not vary across affected CBGs.

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*) are set to zero, which corresponds to "unspecified" or "all" recreational uses in the meta-data.[127] 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.

**Table G-3. Independent Variable Assignments for Surface Water Quality Meta-Analysis**

| Variable | Coefficient | | Assigned Value | Explanation |
|---|---|---|---|---|
| | Model 1 | Model 2 | | |
| **Study Methodology and Year** | | | | |
| intercept | -2.823 | -10.020 | | |
| OneShotVal | 0.247 | 0.552 | 1 | Binary variable indicating that the study's survey only included one valuation question. Set to one because one valuation scenario follows best practices for generating incentive-compatible WTP estimates (Carson *et al.*, 2014; Johnston, Boyle, *et al.*, 2017). |
| tax_only | -0.177 | -0.478 | 1 | Binary variable indicating that the payment mechanism used to elicit WTP is increased taxes. Set to one because using taxes as the payment mechanism generates incentive-compatible WTP estimates and is inclusive of both users and nonusers. |
| user_cost | -0.873 | -1.199 | 0 | Binary variable indicating that the payment mechanism used to elicit WTP is increased user cost. Set to zero because user cost payment mechanisms are less inclusive of nonusers than tax-based payment mechanisms. |
| RUM | 0.901 | 0.680 | 1 | Binary variable indicating that the study used a Random Utility Model (RUM) to estimate WTP. Set to one because use of a RUM to estimate WTP is a standard best practice in modern stated preference studies. |
| IBI | -2.355 | -2.185 | 0 | Binary variable indicating that the study used the IBI as the water quality metric. Set to zero because the meta-regression uses the WQI as the water quality metric, not the IBI. |
| lnyear | -0.135 | -0.362 | ln(2017-1980) | 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 maximum value from the meta-data (ln(2017-1980)) to reflect a time trend interpretation of the variable. |

[127] If a particular recreational use was not specified in the survey instrument, EPA assessed that survey respondents were thinking of all relevant uses.

**Table G-3. Independent Variable Assignments for Surface Water Quality Meta-Analysis**

| Variable | Coefficient | | Assigned Value | Explanation |
|---|---|---|---|---|
| | Model 1 | Model 2 | | |
| volunt | -1.656 | -1.870 | 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 (Johnston, Boyle*, et al.*, 2017). |
| non_reviewed | -0.233 | -0.247 | 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. |
| thesis | 0.431 | 0.580 | 0 | Binary variable indicating that the study is a thesis or dissertation. Set to zero because studies published in peer-reviewed journals are preferred. |
| lump_sum | 0.534 | 0.518 | 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. |
| **Region and Surveyed Population** | | | | |
| census_south | 0.693 | 0.990 | Varies | Binary variable indicating that the affected waters are located entirely within the South Census region, which includes the following states: DE, MD, DC, WV, VA, NC, SC, GA, FL, KY, TN, MS, AL, AR, LA, OK, and TX. Set based on the state in which the CBG is located. |
| census_midwest | 0.667 | 0.945 | Varies | Binary variable indicating that the affected waters are located entirely within the Midwest Census region, which includes the following states: OH, MI, IN, IL, WI, MN, IA, MO, ND, SD, NE, and KS. Set based on the state in which the CBG is located. |
| census_west | 0.393 | 0.400 | Varies | Binary variable indicating that the affected waters are located entirely within the West Census region, which includes the following states: MT, WY, CO, NM, ID, UT, AZ, NV, WA, OR, and CA. Set based on the state in which the CBG is located. |
| nonusers | -0.283 | -0.380 | 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 water quality changes for all households, including users and nonusers. |
| lnincome | 0.478 | 1.199 | 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** | | | | |
| swim_use | 0.300 | 0.361 | 0 | Binary variables that identify studies in which swimming and gamefish uses are specifically identified. Set to zero, which corresponds to all recreational uses, since data on specific recreational uses of the reaches affected by steam electric power plant discharges are not available. |
| gamefish | 0.871 | 0.531 | 0 | |

**Table G-3. Independent Variable Assignments for Surface Water Quality Meta-Analysis**

| Variable | Coefficient | | Assigned Value | Explanation |
|---|---|---|---|---|
| | Model 1 | Model 2 | | |
| ln_ar_agr | -0.572 | -0.654 | 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 | -0.157 | -0.153 | 3.675 | 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 COMIDs in scope of the analysis, while *ar_total_area* is set based on the area of counties intersecting each affected reach (COMID). *ln_ar_ratio* is set to the mean value from all COMIDs within the scope of the analysis. |
| sub_proportion | 0.993 | 0.650 | 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** | | | | |
| ln_Q | -0.666 | -0.259 | Varies | Because WTP for a one-point improvement on the WQI is assumed to depend on both baseline water quality and expected water quality under the regulatory option, this variable is set to the natural log of 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 | -0.683 | ln(7)<br>ln(20) | *ln_quality_ch* was set to the natural log of ΔWQI=7 or ΔWQI=20 for high and low estimates of one-point WTP, respectively. |

# Appendix 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 199 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 (2025-2029) or Period 2 (2030-2049). As shown in the table, several species of amphibians, birds, clams, fishes, mammals, and reptiles have habitat ranges overlapping reaches with baseline exceedances in Period 1. There are no additional exceedances under any of the regulatory options, but water quality improvements under Option 3 and Option 4 reduce the number of exceedances from the baseline conditions.

**Table H-1: Number of T&E Species with Habitat Range Intersecting Reaches Downstream from Steam Electric Power Plant Outfalls, by Species Group**

| Species Name | Number of Reaches with NRWQC Exceedances for at Least One Pollutant Intersecting Habitat Ranges of T&E Species | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Period 1 | | | | | Period 2 | | | | |
| | Baseline | Option 1 | Option 2 | Option 3 | Option 4 | Baseline | Option 1 | Option 2 | Option 3 | Option 4 |
| Amphibians | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Arachnids | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Birds | 6 | 6 | 6 | 4 | 4 | 4 | 4 | 3 | 3 | 3 |
| Clams | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 |
| Crustaceans | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Fishes | 3 | 3 | 3 | 1 | 1 | 1 | 1 | 0 | 0 | 0 |
| Insects | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Mammals | 5 | 5 | 5 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Reptiles | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Snails | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Total** | **28** | **28** | **28** | **23** | **23** | **23** | **23** | **21** | **21** | **21** |

*Source: U.S. EPA Analysis, 2022*

Table H-2 provides further details on the 199 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:

- 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 1 | Option 2 | Option 3 | Option 4 | Baseline | Option 1 | Option 2 | Option 3 | Option 4 |
| Amphibians | 8 | *Ambystoma bishopi* | Moderate | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Ambystoma cingulatum* | Moderate | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 |
| | | *Cryptobranchus alleganiensis bishopi* | Higher | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Necturus alabamensis* | Higher | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Phaeognathus hubrichti* | Lower | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Plethodon nettingi* | Lower | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Rana pretiosa* | Higher | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Rana sevosa* | Lower | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Arachnids | 6 | *Cicurina baronia* | Lower | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Cicurina madla* | Lower | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Cicurina venii* | Lower | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Cicurina vespera* | Lower | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Neoleptoneta microps* | Lower | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Texella cokendolpheri* | Lower | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Birds | 26 | *Ammodramus savannarum floridanus* | Lower | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Aphelocoma coerulescens* | Lower | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Brachyramphus marmoratus* | Moderate | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Calidris canutus rufa* | Lower | 23 | 23 | 23 | 23 | 23 | 23 | 23 | 23 | 23 | 23 |
| | | *Campephilus principalis* | Lower | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Charadrius melodus* | Moderate | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 2 | 2 | 2 |
| | | *Coccyzus americanus* | Lower | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Dendroica chrysoparia* | Lower | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Empidonax traillii extimus* | Lower | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Eremophila alpestris strigata* | Lower | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Falco femoralis septentrionalis* | Lower | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Grus americana* | Moderate | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Grus canadensis pulla* | Moderate | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Gymnogyps californianus* | Lower | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Laterallus jamaicensis ssp. jamaicensis* | Lower | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Mycteria americana* | Moderate | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 |

**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 1 | Option 2 | Option 3 | Option 4 | Baseline | Option 1 | Option 2 | Option 3 | Option 4 |
| | | *Numenius borealis* | Lower | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Phoebastria (=Diomedea) albatrus* | Lower | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Picoides borealis* | Lower | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 |
| | | *Polyborus plancus audubonii* | Lower | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Rostrhamus sociabilis plumbeus* | Lower | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Sterna antillarum* | Higher | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Sterna dougallii dougallii* | Lower | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Strix occidentalis lucida* | Lower | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Tympanuchus cupido attwateri* | Lower | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Vermivora bachmanii* | Moderate | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Clams | 63 | *Amblema neislerii* | Higher | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Cumberlandia monodonta* | Higher | 17 | 17 | 17 | 17 | 17 | 17 | 17 | 17 | 17 | 17 |
| | | *Cyprogenia stegaria* | Higher | 18 | 18 | 18 | 18 | 18 | 18 | 18 | 18 | 18 | 18 |
| | | *Dromus dromas* | Higher | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Elliptio chipolaensis* | Higher | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Elliptio lanceolata* | Higher | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Elliptio spinosa* | Higher | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Elliptoideus sloatianus* | Higher | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Epioblasma brevidens* | Higher | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Epioblasma capsaeformis* | Higher | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Epioblasma florentina florentina* | Higher | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Epioblasma florentina walkeri (=E. walkeri)* | Higher | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Epioblasma metastriata* | Higher | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Epioblasma obliquata obliquata* | Higher | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Epioblasma othcaloogensis* | Higher | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Epioblasma torulosa gubernaculum* | Higher[a] | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Epioblasma torulosa rangiana* | Higher | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Epioblasma torulosa torulosa* | Higher | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Epioblasma triquetra* | Higher | 17 | 17 | 17 | 17 | 17 | 17 | 17 | 17 | 17 | 17 |
| | | *Epioblasma turgidula* | Higher | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Fusconaia cor* | Higher | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Fusconaia cuneolus* | Higher | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Fusconaia masoni* | Higher | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Hemistena lata* | Higher | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Lampsilis abrupta* | Higher | 19 | 19 | 19 | 19 | 19 | 19 | 19 | 19 | 19 | 19 |
| | | *Lampsilis altilis* | Higher | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Lampsilis higginsii* | Higher | 0 | 0 | 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 1 | Option 2 | Option 3 | Option 4 | Baseline | Option 1 | Option 2 | Option 3 | Option 4 |
| | | *Lampsilis perovalis* | Higher | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Lampsilis rafinesqueana* | Higher | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Lampsilis subangulata* | Higher | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Lampsilis virescens* | Higher | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Lasmigona decorata* | Higher | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Lemiox rimosus* | Higher | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Leptodea leptodon* | Higher | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Margaritifera hembeli* | Higher | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Margaritifera marrianae* | Higher | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Medionidus acutissimus* | Higher | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Medionidus parvulus* | Higher | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Medionidus penicillatus* | Higher | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Obovaria retusa* | Higher | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| | | *Plethobasus cicatricosus* | Higher | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Plethobasus cooperianus* | Higher | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| | | *Plethobasus cyphyus* | Higher | 18 | 18 | 18 | 18 | 18 | 18 | 18 | 18 | 18 | 18 |
| | | *Pleurobema clava* | Higher | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| | | *Pleurobema collina* | Higher | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Pleurobema decisum* | Higher | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Pleurobema furvum* | Higher | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Pleurobema georgianum* | Higher | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Pleurobema hanleyianum* | Higher | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Pleurobema perovatum* | Higher | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Pleurobema plenum* | Higher | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| | | *Pleurobema pyriforme* | Higher | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Pleurobema taitianum* | Higher | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Pleuronaia dolabelloides* | Higher | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Potamilus capax* | Higher | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Potamilus inflatus* | Higher | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Ptychobranchus greenii* | Higher | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Quadrula cylindrica cylindrica* | Higher | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Quadrula cylindrica strigillata* | Higher[b] | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Quadrula fragosa* | Higher | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Quadrula intermedia* | Higher | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Villosa fabalis* | Higher[b] | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Villosa perpurpurea* | Higher | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Crustaceans | 5 | *Antrolana lira* | Higher | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Cambarus aculabrum* | Higher | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Gammarus acherondytes* | Moderate | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Orconectes shoupi*[c] | Higher | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Palaemonias alabamae* | Moderate | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Fishes | 35 | *Acipenser oxyrinchus (=oxyrhynchus) desotoi* | Higher | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Amblyopsis rosae* | Higher | 0 | 0 | 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 1 | Option 2 | Option 3 | Option 4 | Baseline | Option 1 | Option 2 | Option 3 | Option 4 |
| | | *Chrosomus saylori* | Higher[b] | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Cottus specus* | Higher[b] | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Cyprinella caerulea* | Higher | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Elassoma alabama* | Higher[b] | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Erimonax monachus* | Higher | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Erimystax cahni* | Higher | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Etheostoma boschungi* | Higher | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Etheostoma chienense* | Higher | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Etheostoma etowahae* | Higher | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Etheostoma nianguae* | Higher | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Etheostoma osburni* | Higher[b] | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Etheostoma phytophilum* | Higher | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Etheostoma rubrum* | Higher | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Etheostoma scotti* | Higher | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Etheostoma sellare* | Higher | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Etheostoma trisella* | Higher | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Fundulus julisia* | Higher[b] | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Gila cypha* | Higher | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Gila elegans* | Higher | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Notropis cahabae* | Higher | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Notropis girardi* | Higher | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Notropis topeka (=tristis)* | Higher | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 2 | 2 | 2 |
| | | *Noturus flavipinnis* | Higher | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Oncorhynchus clarkii stomias* | Higher | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Percina aurora* | Higher | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Percina rex* | Higher | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Percina tanasi* | Higher | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Ptychocheilus lucius* | Higher | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Salvelinus confluentus* | Higher | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Scaphirhynchus albus* | Higher | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Scaphirhynchus suttkusi* | Higher | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Speoplatyrhinus poulsoni* | Higher[b] | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Xyrauchen texanus* | Higher | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Insects | 10 | *Batrisodes venyivi* | Lower | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Bombus affinis* | Lower | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Cicindelidia floridana* | Lower | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Hesperia dacotae* | Lower | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Lycaeides melissa samuelis* | Lower | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Neonympha mitchellii mitchellii* | Lower | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Nicrophorus americanus* | Lower | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Rhadine exilis* | Lower | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Rhadine infernalis* | Lower | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Somatochlora hineana* | Higher | 0 | 0 | 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 1 | Option 2 | Option 3 | Option 4 | Baseline | Option 1 | Option 2 | Option 3 | Option 4 |
| Mammals | 16 | *Canis lupus* | Lower | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Corynorhinus (=Plecotus) townsendii ingens* | Lower | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Corynorhinus (=Plecotus) townsendii virginianus* | Lower | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Herpailurus (=Felis) yagouaroundi cacomitli* | Lower | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Leopardus (=Felis) pardalis* | Lower | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Lynx canadensis* | Lower | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Mustela nigripes* | Lower | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Myotis grisescens* | Moderate | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| | | *Myotis septentrionalis* | Lower | 35 | 35 | 35 | 35 | 35 | 35 | 35 | 30 | 30 | 30 |
| | | *Myotis sodalis* | Lower | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 |
| | | *Peromyscus polionotus phasma* | Lower | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Puma (=Felis) concolor coryi* | Lower | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Thomomys mazama pugetensis* | Lower | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Thomomys mazama tumuli* | Lower | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Thomomys mazama yelmensis* | Lower | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Trichechus manatus* | Higher | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| Reptiles | 19 | *Caretta caretta* | Lower | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| | | *Chelonia mydas* | Lower | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| | | *Clemmys muhlenbergii* | Moderate | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Crocodylus acutus* | Lower | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Dermochelys coriacea* | Lower | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| | | *Drymarchon corais couperi* | Lower | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Eretmochelys imbricata* | Lower | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| | | *Eumeces egregius lividus* | Lower | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Gopherus polyphemus* | Lower | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Graptemys flavimaculata* | Higher | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Lepidochelys kempii* | Lower | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Neoseps reynoldsi* | Lower | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Pituophis melanoleucus lodingi* | Lower | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Pituophis ruthveni* | Lower | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Pseudemys alabamensis* | Higher | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Sistrurus catenatus* | Lower | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Sternotherus depressus* | Higher | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Thamnophis eques megalops* | Lower | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Thamnophis rufipunctatus* | Lower | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Snails | 11 | *Athearnia anthonyi* | Higher | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Campeloma decampi* | Higher | 0 | 0 | 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 1 | Option 2 | Option 3 | Option 4 | Baseline | Option 1 | Option 2 | Option 3 | Option 4 |
| | | *Discus macclintocki* | Lower | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Elimia crenatella* | Higher | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Leptoxis foremani* | Higher | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Leptoxis taeniata* | Higher | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Lioplax cyclostomaformis* | Higher | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Pleurocera foremani* | Higher | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Pyrgulopsis ogmorhaphe* | Higher | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Triodopsis platysayoides* | Lower | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Tulotoma magnifica* | Higher | 0 | 0 | 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, 2022*

# Appendix I Methodology for Modeling Air Quality Changes for the Proposed Rule

As noted in Chapter 8, EPA used photochemical modeling to create air quality surfaces[128] that were then used in air pollution benefits calculations of the proposed rule (*i.e.*, Option 3). The modeling-based surfaces captured air pollution impacts resulting from changes in electricity generation profiles 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 the source apportionment modeling and associated 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 3 for 7 analytic years: 2028, 2030, 2035, 2040, 2045, and 2050. EPA created air quality surfaces for the following pollutants and metrics: annual average $PM_{2.5}$; April-September average of 8-hr daily maximum (MDA8) ozone (AS-MO3).

The ozone source apportionment modeling outputs are the same as those created for the *Regulatory Impact Analysis for the proposed Federal Implementation Plan Addressing Regional Ozone Transport for the 2015 Ozone National Ambient Air Quality Standard* (U.S. EPA, 2022c). New $PM_{2.5}$ source apportionment modeling outputs were created using the same inputs and modeling configuration as were used for the available ozone source apportionment modeling. The basic methodology for determining air quality changes is the same as that used in the RIAs from multiple previous rules (U.S. EPA, 2019g, 2020a, 2020b, 2021b, 2022c). EPA calculated baseline and Option 3 scenario EGU emissions estimates of $NO_x$ and $SO_2$ for all seven IPM model years from the Integrated Planning Model (IPM) (Chapter 5 of the RIA; U.S. EPA, 2020e). EPA also used IPM outputs to estimate EGU emissions of $PM_{2.5}$ based on emission factors described in U.S. EPA (2020c). This appendix provides additional details on the source apportionment modeling simulations and on the methods used to translate these emissions scenarios into air quality surfaces.

## I.1 Air Quality Modeling Simulations

The air quality modeling utilized a 2016-based modeling platform which included meteorology and base year emissions from 2016 and projected emissions for 2026.[129,130] The air quality modeling included photochemical model simulations for a 2016 base year and 2026 future year to provide hourly concentrations of ozone and $PM_{2.5}$ component species nationwide. In addition, source apportionment modeling was performed for 2026 to quantify the contributions to ozone from $NO_X$ emissions from electric generating units (EGUs) and to $PM_{2.5}$ from $NO_X$, $SO_2$ and directly emitted $PM_{2.5}$ emissions on a state-by-state basis. As described below, the modeling results for 2016 and 2026, in conjunction with EGU emissions data for the baseline and proposed rule option 3 in 2028, 2030, 2035, 3040, 2045, and 2050 were used to construct the air quality surfaces that reflect the influence of emissions changes between the baseline and the option 3 in each year.

128 "air quality surfaces" refers to continuous gridded spatial fields using a 12-km grid-cell resolution

129 Information on the emissions inventories used for the modeling described in Preparation of Emissions Inventories for the 2016v2 North American Emissions Modeling Platform

130 The air quality modeling performed to support the analyses in this proposed RIA can be found in the Air Quality Modeling Technical Support Document Federal Implementation Plan Addressing Regional Ozone Transport for the 2015 Ozone National Ambient Air Quality Standards Proposed Rulemaking

The air quality model simulations (*i.e.*, model runs) were performed using the Comprehensive Air Quality Model with Extensions (CAMx) version 7.10[131] (Ramboll Environ, 2020). The nationwide 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 I-1. Model predictions of ozone and $PM_{2.5}$ concentrations were compared against ambient measurements (U.S. EPA, 2022a; 2022b). Ozone and $PM_{2.5}$ model evaluations showed model performance that was adequate for applying these model simulations for the purpose of creating air quality surfaces to estimate ozone and $PM_{2.5}$ benefits.

**Figure I-1: Air Quality Modeling Domain**


The contributions to ozone and $PM_{2.5}$ component species (*e.g.*, sulfate, nitrate, ammonium, elemental carbon (EC), organic aerosol (OA), and crustal material[132]) from EGU emissions in individual states were modeled using the "source apportionment" tool. 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[133] contributions from the emissions in each individual tag to hourly modeled concentrations. For this RIA we used the source apportionment contribution data to provide a means to 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. Specifically, we applied outputs from source apportionment modeling for ozone and $PM_{2.5}$ component species using the 2026 modeled case to obtain the contributions from EGUs emissions in each state to ozone and $PM_{2.5}$ component species concentrations in each 12 x 12 km model grid cell nationwide. Ozone contributions were modeled using the Anthropogenic Precursor Culpability Assessment (APCA) tool and $PM_{2.5}$ contributions were modeled suing the Particulate Matter Source Apportionment Technology (PSAT) tool (Ramboll Environ, 2020). The ozone source apportionment modeling was performed for the period April through September to provide data for developing spatial fields for the April through September maximum daily eight hour (MDA8) (*i.e.*, AS-MO3) average ozone

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131 This CAMx simulation set the Rscale $NH_3$ dry deposition parameter to 0 which resulted in more realistic model predictions of $PM_{2.5}$ nitrate concentrations than using a default Rscale parameter of 1

132 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.

133 Hourly contribution information is provided for each grid cell to provide spatial patterns of the contributions from each tag

concentration exposure metric. The $PM_{2.5}$ source apportionment modeling was performed for a full-year to provide data for developing annual average $PM_{2.5}$ spatial fields. Table I-1 provides state-level 2026 EGU emissions that were tracked for each source apportionment tag.

**Table I-1: 2026 emissions (tons) allocated to each modeled state-EGU source apportionment tag**

| State Tag | Ozone Season $NO_X$ Emissions | Annual $NO_X$ emissions | Annual $SO_2$ emissions | Annual $PM_{2.5}$ emissions |
|---|---|---|---|---|
| AL | 6,205 | 9,319 | 1,344 | 2,557 |
| AR | 5,594 | 9,258 | 22,306 | 1,075 |
| AZ | 1,341 | 3,416 | 2,420 | 814 |
| CA | 6,627 | 16,286 | 249 | 4,810 |
| CO | 5,881 | 12,725 | 7,311 | 1,556 |
| CT | 1,673 | 3,740 | 845 | 467 |
| DC | 37 | 39 | 0 | 53 |
| DE | 203 | 320 | 126 | 119 |
| FL | 11,590 | 22,451 | 8,784 | 6,555 |
| GA | 3,199 | 5,937 | 1,177 | 2,452 |
| IA | 8,008 | 17,946 | 9,042 | 1,182 |
| ID | 375 | 705 | 1 | 185 |
| IL | 8,244 | 16,777 | 31,322 | 3,018 |
| IN | 11,052 | 36,007 | 34,990 | 6,281 |
| KS | 3,166 | 4,351 | 854 | 709 |
| KY | 11,894 | 25,207 | 22,940 | 10,476 |
| LA | 10,895 | 16,949 | 11,273 | 3,119 |
| MA | 2,115 | 4,566 | 839 | 384 |
| MD | 1,484 | 3,008 | 273 | 783 |
| ME | 1,233 | 3,063 | 1,147 | 414 |
| MI | 11,689 | 22,378 | 31,387 | 3,216 |
| MN | 4,192 | 9,442 | 7,189 | 481 |
| MO | 10,075 | 34,935 | 105,916 | 3,617 |
| MS | 3,631 | 5,208 | 30 | 1,240 |
| MT | 3,908 | 8,760 | 3,527 | 1,426 |
| NC | 7,175 | 15,984 | 6,443 | 2,720 |
| ND | 8,053 | 19,276 | 26,188 | 1,265 |
| NE | 8,670 | 20,274 | 45,869 | 1,530 |
| NH | 224 | 483 | 159 | 93 |
| NJ | 1,969 | 4,032 | 915 | 729 |
| NM | 1,266 | 1,987 | 0 | 304 |
| NV | 1,577 | 3,017 | 0 | 901 |
| NY | 6,248 | 11,693 | 1,526 | 1,649 |
| OH | 9,200 | 27,031 | 46,780 | 4,543 |
| OK | 2,412 | 3,426 | 2 | 828 |
| OR | 1,122 | 2,145 | 29 | 455 |
| PA | 12,386 | 23,965 | 9,685 | 3,785 |
| RI | 233 | 476 | 0 | 68 |
| SC | 3,251 | 7,134 | 6,292 | 2,082 |
| SD | 478 | 1,054 | 889 | 55 |
| TL* | 1,337 | 2,970 | 6,953 | 1,329 |

| Table I-1: 2026 emissions (tons) allocated to each modeled state-EGU source apportionment tag | | | | |
|---|---|---|---|---|
| State Tag | Ozone Season $NO_X$ Emissions | Annual $NO_X$ emissions | Annual $SO_2$ emissions | Annual $PM_{2.5}$ emissions |
| TN | 790 | 2,100 | 1,231 | 845 |
| TX | 16,548 | 27,164 | 19,169 | 5,027 |
| UT | 3,571 | 10,915 | 11,040 | 693 |
| VA | 3,607 | 7,270 | 820 | 1,805 |
| VT | 2 | 4 | 0 | 4 |
| WA | 11,78 | 2,532 | 158 | 384 |
| WI | 2,097 | 4,304 | 821 | 1,084 |
| WV | 7,479 | 21,450 | 28,513 | 2,180 |
| WY | 5,026 | 11,036 | 8,725 | 629 |

* TL represents emissions occurring on tribal lands

Examples of the magnitude and spatial extent of ozone and $PM_{2.5}$ contributions are provided in Figure I-2 through Figure I-5 for EGUs in California, Texas, Iowa, and Ohio. These figures show how the magnitude and the spatial patterns of contributions of EGU emissions to ozone and $PM_{2.5}$ component species depend on multiple factors including the magnitude and location of emissions as wells as the atmospheric conditions that influence the formation and transport of these pollutants. For instance, $NO_x$ emissions are a precursor to both ozone and $PM_{2.5}$ nitrate. However, ozone and nitrate form under very different types of atmospheric conditions with ozone formation occurring in locations with ample sunlight and ambient volatile organic compound (VOC) concentrations while nitrate formation requires colder and drier conditions and the presence of gas-phase ammonia. California's complex terrain that tends to trap air and allow pollutant build-up combined with warm sunny summer and cooler dry winters and sources of both ammonia and VOCs make its atmosphere conducive to formation of both ozone and nitrate. While the magnitude of EGU NOx emissions in Iowa and California are similar in the 2026 modeling (Table I-1), the emissions from California lead to larger contributions to those pollutants due to the conducive conditions in that state. Texas and Ohio both had larger $NO_x$ emissions than California or Iowa. While maximum ozone impacts shown for Texas and Ohio EGUs are similar order of magnitude to maximum ozone impacts from California EGUs, nitrate impacts are much smaller in Ohio and negligible in Texas due to less conducive atmospheric conditions for nitrate formation in those locations. California EGU $SO_2$ emissions in the 2026 modeling are several orders of magnitude smaller than $SO_2$ emissions in Ohio and Texas (Table I-1) leading to much smaller sulfate contributions from California EGUs than from Ohio and Texas EGUs. $PM_{2.5}$ organic aerosol EGU contributions in this modeling come from primary $PM_{2.5}$ emissions rather than secondary atmospheric formation. Consequently, the impacts of EGU emissions on this pollutant tend to occur closer to the EGU sources than impacts of secondary pollutants (ozone, nitrate, and sulfate) which have spatial patterns showing broader regional impacts. These patterns demonstrate how the model is able capture important atmospheric processes which impact pollutant formation and transport form emissions sources.

**Figure I-2: Map of California EGU Tag Contributions to a) April-September Seasonal Average MDA8 Ozone (ppb) b) Annual $PM_{2.5}$ Nitrate (µg/m$^3$) c) Annual $PM_{2.5}$ sulfate (µg/m$^3$) d) Annual $PM_{2.5}$ Organic Aerosol (µg/m$^3$)**

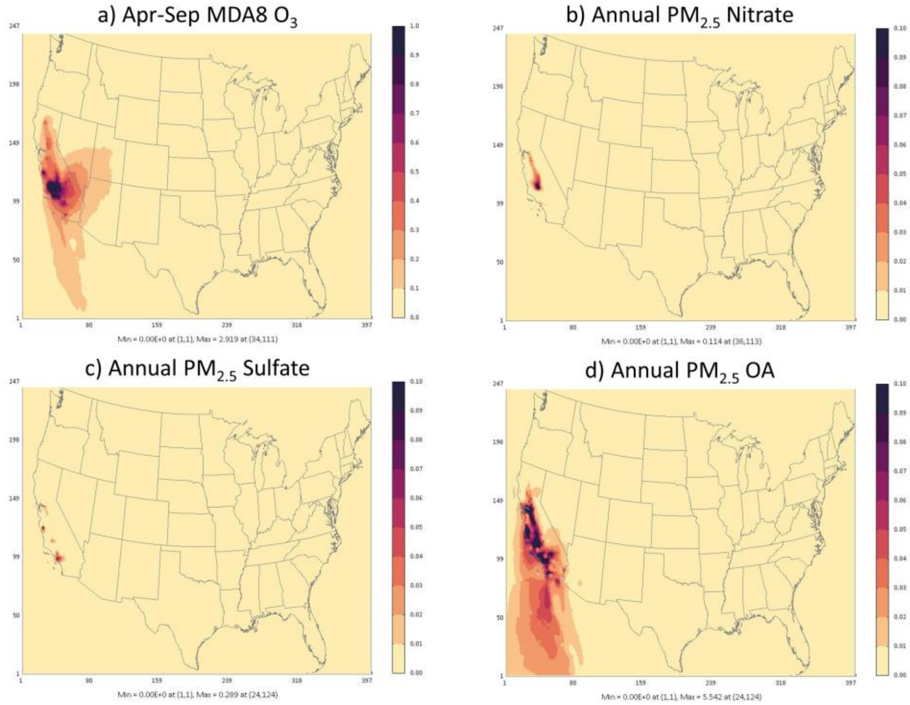



**Figure I-3: Map of Texas EGU Tag Contributions to a) April-September Seasonal Average MDA8 Ozone (ppb) b) Annual $PM_{2.5}$ Nitrate (µg/m$^3$) c) Annual $PM_{2.5}$ sulfate (µg/m$^3$) d) Annual $PM_{2.5}$ Organic Aerosol (µg/m$^3$)**

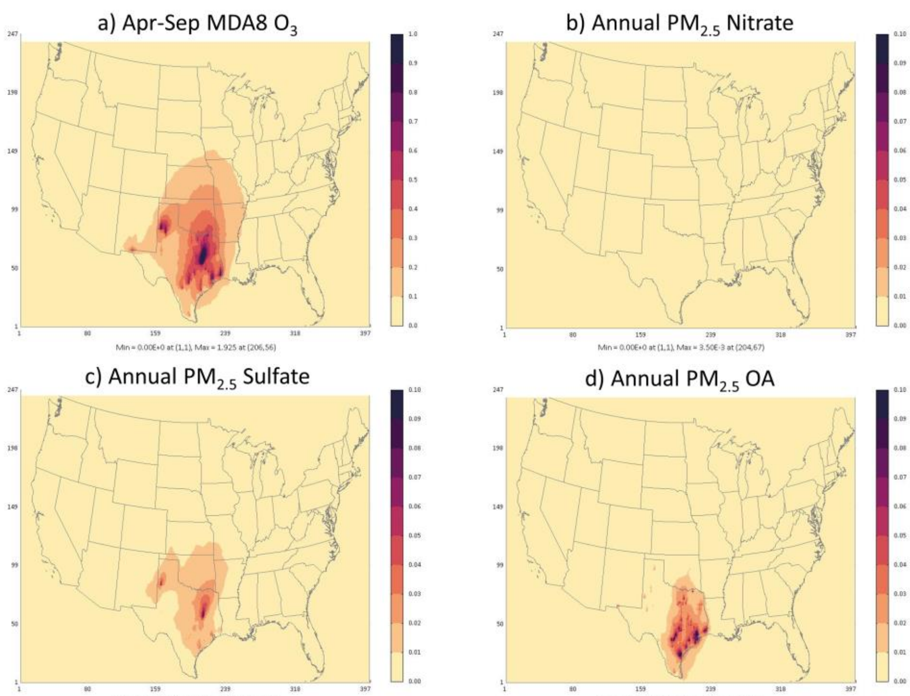


**Figure I-4: Map of Iowa EGU Tag Contributions to a) April-September Seasonal Average MDA8 Ozone (ppb) b) Annual $PM_{2.5}$ Nitrate (µg/m$^3$) c) Annual $PM_{2.5}$ sulfate (µg/m$^3$) d) Annual $PM_{2.5}$ Organic Aerosol (µg/m$^3$)**

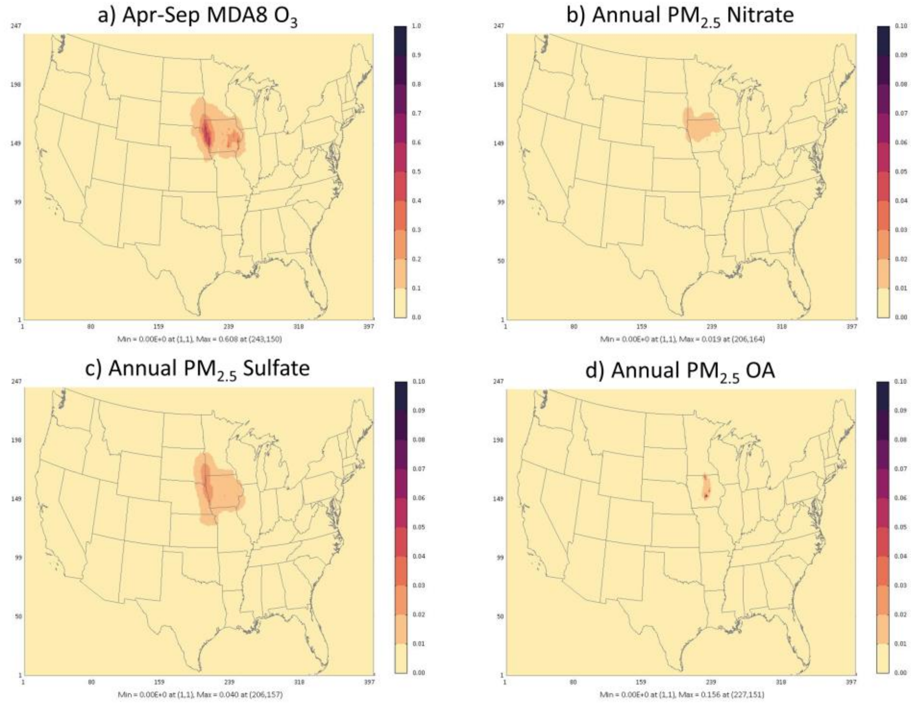
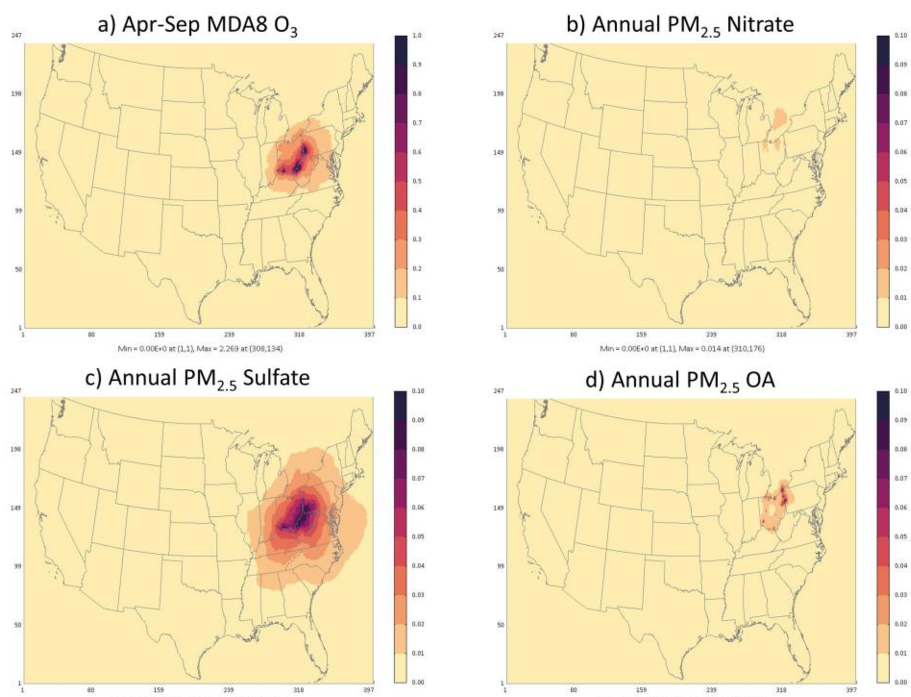



**Figure I-5: Map of Ohio EGU Tag Contributions to a) April-September Seasonal Average MDA8 Ozone (ppb) b) Annual $PM_{2.5}$ Nitrate (µg/m$^3$) c) Annual $PM_{2.5}$ sulfate (µg/m$^3$) d) Annual $PM_{2.5}$ Organic Aerosol (µg/m$^3$)**



## I.2 Applying Modeling Outputs to Create Spatial Fields

In this section we describe the method for creating spatial fields of AS-MO3 and annual average $PM_{2.5}$ based on the 2016 and 2026 modeling. The foundational data include (1) ozone and speciated $PM_{2.5}$ concentrations in each model grid cell from the 2016 and 2026 modeling, (2) ozone and speciated $PM_{2.5}$ contributions in 2026 of EGUs emissions from each state in each model grid cell[134], (3) 2026 emissions from EGUs that were input to the contribution modeling, and (4) the EGU emissions for baseline and policy scenarios in each year of analysis (2028, 2030, 2035, 2040, 2045, 2050) generated from IPM. The method to create spatial fields applies scaling factors based on emissions changes between 2026 projections and the baseline and the control cases to the 2026 contributions. This method is described in detail below.

Spatial fields of ozone and $PM_{2.5}$ in 2026 were created based on “fusing” modeled data with measured concentrations at air quality monitoring locations. To create the spatial fields for each future emissions scenario these fused 2026 model fields are used in combination with 2026 state-EGU source apportionment modeling and the EGU emissions for each scenario and analytic year[135]. Contributions from each state-EGU contribution “tag” were scaled based on the ratio of emissions in the year/scenario being evaluated to the emissions in the modeled 2026 scenario. Contributions from tags representing sources other than EGUs are held constant at 2026 levels for each of the scenarios and year. For each scenario and year analyzed, the scaled contributions from all sources were summed together to create a gridded surface of total modeled ozone and $PM_{2.5}$. The process is described in a step-by-step manner below starting with the methodology for creating AS-MO3 spatial fields followed by a description of the steps for creating annual $PM_{2.5}$ spatial fields.

### Ozone

1. Create fused spatial fields of 2026 AS-MO3 incorporating information from the air quality modeling and from ambient measured monitoring data. The enhanced Voronoi Neighbor Average (eVNA) technique (Gold et al., 1997; US EPA, 2007; Ding et al., 2015) was applied to ozone model predictions in conjunction with measured data to create modeled/measured fused surfaces that leverage measured concentrations at air quality monitor locations and model predictions at locations with no monitoring data.
    - 1.1. The AS-MO3 eVNA spatial fields are created for the 2016 base year with EPA’s software package, Software for the Modeled Attainment Test – Community Edition (SMAT-CE) using 3 years of monitoring data (2015-2017) and the 2016 modeled data.
    - 1.2. The model-predicted spatial fields (*i.e.*, not the eVNA fields) of AS-MO3 in 2016 were paired with the corresponding model-predicted spatial fields in 2026 to calculate the ratio of AS-MO3 between 2016 and 2026 in each model grid cell.
    - 1.3. To create a gridded 2026 eVNA surfaces, the spatial fields of 2016/2026 ratios created in step (1.2) were multiplied by the corresponding eVNA spatial fields for 2016 created in step (1.1) to produce an eVNA AS-MO3 spatial field for 2026 using (Eq-1).

$$eVNA_{g,future} = \left(eVNA_{g,2016}\right) \times \frac{Model_{g,future}}{Model_{g,2016}} \qquad \text{Eq-1}$$

- $eVNA_{g,future}$ is the eVNA concentration of AS-MO3 or $PM_{2.5}$ component species in grid-

[134] Contributions from EGUs were modeled using projected emissions for 2026. The resulting contributions were used to construct spatial fields in 2028, 2030, 2035, 2040, 2045, and 2050.

[135] *i.e.*, 2028, 2030, 2035, 2040, 2045, and 2050

cell, g, in the future year

- $eVNA_{g,2016}$ is the eVNA concentration of AS-MO3 or $PM_{2.5}$ component species in grid-cell, g, in 2016
- $Model_{g,future}$ is the CAMx modeled concentration of AS-MO3 or $PM_{2.5}$ component species in grid-cell, g, in the future year
- $Model_{g,2016}$ is the CAMx modeled concentration of AS-MO3 or $PM_{2.5}$ component in grid-cell, g, in 2016

2. Create spatial fields of total EGU AS-MO3 contributions for each combination of scenario and analytic year evaluated.
   - 2.1. Use the EGU ozone season $NO_X$ emissions for the 2028 baseline and the corresponding 2026 modeled EGU ozone season emissions (Table I-1) to calculate the ratio of 2028 baseline emissions to 2026 modeled emissions for each EGU state contribution tag (*i.e.*, an ozone-season $NO_X$ scaling factor calculated for each state)[136]. These scaling factors are provided in Table I-2.
   - 2.2. Calculate adjusted gridded AS-MO3 EGU contributions that reflect differences in state-EGU $NO_X$ emissions between 2026 and the 2028 baseline by multiplying the ozone season $NO_X$ scaling factors by the corresponding gridded AS-MO3 ozone contributions[137] from each state-EGU tag.
   - 2.3. Add together the adjusted AS-MO3 contributions for each EGU-state tag to produce spatial fields of adjusted EGU totals for the 2028 baseline.[138]
   - 2.4. Repeat steps 2.1 through 2.3 for the 2028 option 3 policy scenario and for the baseline and Option 3 scenarios for each additional analytic year. The scaling factors for the baseline scenarios and the Option 3 policy scenarios are provided in Table I-2 and Table I-3 respectively.
3. Create a gridded spatial field of AS-MO3 associated with IPM emissions for the 2028 baseline by combining the EGU AS-MO3 contributions from steps (2.3) with the corresponding contributions to AS-MO3 from all other sources. Repeat for each of the EGU contributions created in step (2.4) to create separate gridded spatial fields for the rest of the baseline and policy scenarios for each analytic year.

[136] Preliminary testing of this methodology showed unstable results when very small magnitudes of emissions were tagged especially when being scaled by large factors. To mitigate this issue, scaling factors of 1.00 were applied to any tags that tracked less than 100 tpy emissions in the original source apportionment modeling. Any emissions changes in the low emissions state were assigned to a nearby state as denoted in Table I-2 through I-9.

[137] The source apportionment modeling provided separate ozone contributions for ozone formed in VOC-limited chemical regimes (O3V) and ozone formed in NOX-limited chemical regimes (O3N). The emissions scaling factors are multiplied by the corresponding O3N gridded contributions to MDA8 concentrations. Since there are no predicted changes in VOC emissions in the control scenarios, the O3V contributions remain unchanged.

[138] The contributions from the unaltered O3V tags are added to the summed adjusted O3N EGU tags.

Steps 2 and 3 in combination can be represented by equation 2:

$$\begin{aligned} AS\text{-}MO3_{g,i,y} &= eVNA_{g,y} \\ &\times \left( \frac{C_{g,BC}}{C_{g,Tot}} + \frac{C_{g,int}}{C_{g,Tot}} + \frac{C_{g,bio}}{C_{g,Tot}} + \frac{C_{g,fires}}{C_{g,Tot}} + \frac{C_{g,USanthro}}{C_{g,Tot}} + \sum_{t=1}^{T} \frac{C_{EGUVOC,g,t}}{C_{g,Tot}} \right. \\ &\left. + \sum_{t=1}^{T} \frac{C_{EGUNOx,g,t}\, S_{NOx,t,i,y}}{C_{g,Tot}} \right) \end{aligned} \qquad \text{Eq-2}$$

- $AS\text{-}MO3_{g,i,y}$ is the estimated fused model-obs AS-MO3 for grid-cell, "g", scenario, "i"[139], and year, "y"[140];
- $eVNA_{g,y}$ is the eVNA future year AS-MO3 for grid-cell "g" and year "y" calculated using Eq-1.
- $C_{g,Tot}$ is the total modeled AS-MO3 for grid-cell "g" from all source in the 2026 source apportionment modeling
- $C_{g,BC}$ is the 2026 AS-MO3 modeled contribution from the modeled boundary inflow;
- $C_{g,int}$ is the 2026 AS-MO3 modeled contribution from international emissions within the modeling domain;
- $C_{g,bio}$ is the 2026 AS-MO3 modeled contribution from biogenic emissions;
- $C_{g,fires}$ is the 2026 AS-MO3 modeled contribution from fires;
- $C_{g,USanthro}$ is the total 2026 AS-MO3 modeled contribution from U.S. anthropogenic sources other than EGUs;
- $C_{EGUVOC,g,t}$ is the 2026 AS-MO3 modeled contribution from EGU emissions of VOCs from state, "t";
- $C_{EGUNOx,g,t}$ is the 2026 AS-MO3 modeled contribution from EGU emissions of $NO_X$ from state, "t"; and
- $S_{NOx,t,i,y}$ is the EGU $NO_X$ scaling factor for state, "t", scenario "i", and year, "y".

### $PM_{2.5}$

4. Create fused spatial fields of 2026 annual $PM_{2.5}$ component species incorporating information from the air quality modeling and from ambient measured monitoring data. The eVNA technique was applied to $PM_{2.5}$ component species model predictions in conjunction with measured data to create modeled/measured fused surfaces that leverage measured concentrations at air quality monitor locations and model predictions at locations with no monitoring data.
   4.1. The quarterly average $PM_{2.5}$ component species eVNA spatial fields are created for the 2016 base year with EPA's SMAT-CE software package using 3 years of monitoring data (2015-2017) and the

139 Scenario "i" can represent either baseline or regulatory proposal scenario.

140 Year "y" can represent 2028, 2030, 2035, 2040, 2045, or 2050.

2016 modeled data.

4.2. The model-predicted spatial fields (*i.e.*, not the eVNA fields) of quarterly average $PM_{2.5}$ component species in 2016 were paired with the corresponding model-predicted spatial fields in 2026 to calculate the ratio of $PM_{2.5}$ component species between 2016 and 2026 in each model grid cell.

4.3. To create a gridded 2026 eVNA surfaces, the spatial fields of 2016/2026 ratios created in step (4.2) were multiplied by the corresponding eVNA spatial fields for 2016 created in step (4.1) to produce an eVNA annual average $PM_{2.5}$ component species spatial field for 2026 using (Eq-1).

5. Create spatial fields of total EGU speciated $PM_{2.5}$ contributions for each year/scenario evaluated.

   5.1. Use the EGU annual total $NO_X$, $SO_2$ and $PM_{2.5}$ emissions for the 2028 baseline scenario and the corresponding 2026 modeled EGU $NO_X$, $SO_2$ and $PM_{2.5}$ emissions to calculate the ratio of 2028 baseline emissions to 2026 modeled emissions for each EGU state contribution tag (*i.e.*, annual $NO_X$, $SO_2$ and $PM_{2.5}$ scaling factors calculated for each state)[141]. These scaling factors are provided in Table I-4 through Table I-9.

   5.2. Calculate adjusted gridded annual $PM_{2.5}$ component species EGU contributions that reflect differences in state-EGU $NO_X$, $SO_2$ and primary $PM_{2.5}$ emissions between 2026 and the 2028 baseline by multiplying the annual $NO_X$, $SO_2$ and $PM_{2.5}$ scaling factors by the corresponding annual gridded $PM_{2.5}$ component species contributions from each state-EGU tag[142].

   5.3. Add together the adjusted $PM_{2.5}$ contributions of for each EGU state tag to produce spatial fields of adjusted EGU totals for each $PM_{2.5}$ component species.

   5.4. Repeat steps 5.1 through 5.3 for the 2028 Option 3 scenario and for the baseline and Option 3 scenarios for each additional analytic year. The scaling factors for all $PM_{2.5}$ component species for the baseline and Option 3 scenarios are provided in Table I-4 through Table I-9.

6. Create gridded spatial fields of each $PM_{2.5}$ component species for the 2028 baseline by combining the EGU annual $PM_{2.5}$ component species contributions from step (5.3) with the corresponding contributions to annual $PM_{2.5}$ component species from all other sources. Repeat for each of the EGU contributions created in step (5.4) to create separate gridded spatial fields for the rest of the baseline and policy scenarios and analytic years.

7. Create gridded spatial fields of total $PM_{2.5}$ mass by combining the component species surfaces for sulfate, nitrate, organic aerosol, elemental carbon and crustal material with ammonium, and particle-bound. Ammonium and particle-bound water concentrations are calculated for each scenario based on nitrate and sulfate concentrations along with the ammonium degree of neutralization in the base year modeling in accordance with equations from the SMAT-CE modeling software.

Steps 5 and 6 result in Eq-3 for $PM_{2.5}$ component species: sulfate, nitrate, organic aerosol, elemental carbon and crustal material.

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141 Preliminary testing of this methodology showed unstable results when very small magnitudes of emissions were tagged especially when being scaled by large factors. To mitigate this issue, scaling factors of 1.00 were applied to any tags that had less than 100 tpy emissions in the original source apportionment modeling. Any emissions changes in the low emissions state were assigned to a nearby state as denoted in Table I-2 through I-9.

142 Scaling factors for components that are formed through chemical reactions in the atmosphere were created as follows: scaling factors for sulfate were based on relative changes in annual $SO_2$ emissions; scaling factors for nitrate were based on relative changes in annual $NO_X$ emissions. Scaling factors 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 2026 modeled emissions and the baseline and the Option 3 scenarios in each year.

$$PM_{s,g,i,y} = eVNA_{s,g,y} \times \left( \frac{C_{s,g,BC}}{C_{s,g,Tot}} + \frac{C_{s,g,int}}{C_{s,g,Tot}} + \frac{C_{s,g,bio}}{C_{s,g,Tot}} + \frac{C_{s,g,fires}}{C_{s,g,Tot}} + \frac{C_{s,g,USanthro}}{C_{s,g,Tot}} + \sum_{t=1}^{T} \frac{C_{EGUs,g,t}\, S_{s,t,i,y}}{C_{s,g,Tot}} \right) \quad \text{Eq-3}$$

- $PM_{s,g,i,y}$ is the estimated fused model-obs PM component species "s" for grid-cell, "g", scenario, "i"[143], and year, "y"[144];
- $eVNA_{s,g,y}$ is the eVNA future year PM component species "s" for grid-cell "g" and year "y" calculated using Eq-1.
- $C_{s,g,Tot}$ is the total modeled PM component species "s" for grid-cell "g" from all source in the 2026 source apportionment modeling
- $C_{s,g,BC}$ is the 2026 PM component species "s" modeled contribution from the modeled boundary inflow;
- $C_{s,g,int}$ is the 2026 PM component species "s" modeled contribution from international emissions within the modeling domain;
- $C_{s,g,bio}$ is the 2026 PM component species "s" modeled contribution from biogenic emissions;
- $C_{s,g,fires}$ is the 2026 PM component species "s" modeled contribution from fires;
- $C_{s,g,USanthro}$ is the total 2026 PM component species "s" modeled contribution from U.S. anthropogenic sources other than EGUs;
- $C_{EGUs,g,t}$ is the 2026 PM component species "s" modeled contribution from EGU emissions of $NO_X$, $SO_2$, or primary $PM_{2.5}$ from state, "t"; and
- $S_{s,t,i,y}$ is the EGU scaling factor for component species "s", state, "t", scenario "i", and year, "y". Scaling factors for nitrate are based on annual $NO_x$ emissions, scaling factors for sulfate are based on annual $SO_2$ emissions, scaling factors for primary $PM_{2.5}$ components are based on primary $PM_{2.5}$ emissions.

Selected maps showing changes in air quality concentrations between the Option 3 and the baseline are provided later in this appendix.

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143 Scenario "i" can represent either baseline or regulatory proposal scenario.

144 Year "y" can represent 2028, 2030, 2035, 2040, 2045, or 2050.

## I.3 Scaling Factors Applied to Source Apportionment Tags

**Table I-2: Ozone scaling factors for EGU tags in the baseline scenario**

| State Tag | 2028 | 2030 | 2035 | 2040 | 2045 | 2050 | 2055 |
|---|---|---|---|---|---|---|---|
| AL | 0.92 | 0.94 | 0.73 | 0.86 | 0.71 | 0.73 | 0.73 |
| AR | 1.37 | 0.85 | 0.28 | 0.29 | 0.31 | 0.29 | 0.28 |
| AZ | 0.89 | 0.94 | 1.99 | 1.41 | 1.56 | 1.44 | 1.99 |
| CA | 0.73 | 0.36 | 0.28 | 0.30 | 0.26 | 0.24 | 0.28 |
| CO | 0.90 | 0.50 | 0.15 | 0.17 | 0.16 | 0.15 | 0.15 |
| CT | 0.70 | 0.69 | 0.77 | 0.70 | 0.75 | 0.79 | 0.77 |
| DC | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| DE | 1.36 | 1.38 | 2.06 | 1.88 | 1.93 | 1.97 | 2.06 |
| FL | 0.93 | 0.90 | 0.83 | 0.77 | 0.82 | 0.81 | 0.83 |
| GA | 1.19 | 1.53 | 0.64 | 1.04 | 0.98 | 0.62 | 0.64 |
| IA | 1.27 | 1.30 | 0.65 | 1.07 | 1.04 | 0.65 | 0.65 |
| ID | 1.22 | 1.21 | 0.52 | 1.06 | 0.74 | 0.53 | 0.52 |
| IL | 0.42 | 0.44 | 0.11 | 0.58 | 0.09 | 0.11 | 0.11 |
| IN | 1.13 | 1.12 | 0.22 | 0.71 | 0.59 | 0.21 | 0.22 |
| KS | 1.15 | 0.97 | 0.02 | 0.46 | 0.42 | 0.03 | 0.02 |
| KY | 0.91 | 1.02 | 0.20 | 0.55 | 0.28 | 0.20 | 0.20 |
| LA | 0.83 | 0.82 | 0.42 | 0.55 | 0.51 | 0.36 | 0.42 |
| MA | 1.27 | 1.26 | 1.15 | 1.31 | 1.23 | 1.16 | 1.15 |
| MD | 0.73 | 0.73 | 0.88 | 0.78 | 0.79 | 0.87 | 0.88 |
| ME | 1.79 | 1.32 | 1.30 | 1.33 | 1.33 | 1.30 | 1.30 |
| MI | 1.00 | 0.71 | 0.34 | 0.34 | 0.32 | 0.33 | 0.34 |
| MN | 1.42 | 0.83 | 0.49 | 0.51 | 0.50 | 0.49 | 0.49 |
| MO | 1.34 | 1.06 | 0.53 | 0.80 | 0.58 | 0.53 | 0.53 |
| MS | 0.83 | 0.77 | 0.38 | 0.37 | 0.37 | 0.38 | 0.38 |
| MT | 1.01 | 0.97 | 1.00 | 1.02 | 1.01 | 0.97 | 1.00 |
| NC | 0.50 | 0.36 | 0.07 | 0.16 | 0.14 | 0.07 | 0.07 |
| ND | 1.46 | 1.53 | 0.46 | 0.59 | 0.55 | 0.46 | 0.46 |
| NE | 1.15 | 1.12 | 1.05 | 1.13 | 1.11 | 1.05 | 1.05 |
| NH | 1.13 | 1.17 | 1.16 | 1.13 | 1.13 | 1.16 | 1.16 |
| NJ | 0.97 | 1.00 | 1.16 | 1.02 | 1.07 | 1.09 | 1.16 |
| NM | 0.55 | 0.60 | 0.14 | 0.30 | 0.26 | 0.12 | 0.14 |
| NV | 0.71 | 1.01 | 0.13 | 0.43 | 0.49 | 0.15 | 0.13 |
| NY | 0.91 | 0.79 | 0.54 | 0.51 | 0.52 | 0.54 | 0.54 |
| OH | 0.82 | 0.73 | 0.66 | 0.89 | 0.90 | 0.64 | 0.66 |
| OK | 2.62 | 1.56 | 0.28 | 0.93 | 0.78 | 0.17 | 0.28 |
| OR | 0.37 | 0.10 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| PA | 0.79 | 0.77 | 0.54 | 0.62 | 0.48 | 0.54 | 0.54 |
| RI | 1.22 | 1.21 | 1.42 | 1.20 | 1.28 | 1.41 | 1.42 |
| SC | 1.30 | 1.01 | 1.46 | 1.24 | 1.32 | 1.51 | 1.46 |
| SD | 0.95 | 1.26 | 0.26 | 0.57 | 0.46 | 0.26 | 0.26 |
| TB | 1.08 | 1.08 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 |
| TN | 2.03 | 1.11 | 0.89 | 0.57 | 0.62 | 0.92 | 0.89 |
| TX | 1.09 | 1.10 | 0.65 | 1.02 | 1.11 | 0.63 | 0.65 |
| UT | 2.39 | 2.28 | 0.30 | 1.49 | 0.24 | 0.31 | 0.30 |

| Table I-2: Ozone scaling factors for EGU tags in the baseline scenario | | | | | | | |
|---|---|---|---|---|---|---|---|
| **State Tag** | **2028** | **2030** | **2035** | **2040** | **2045** | **2050** | **2055** |
| VA | 1.10 | 0.79 | 0.55 | 0.88 | 0.69 | 0.54 | 0.55 |
| VT | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| WA | 0.74 | 0.85 | 0.80 | 0.77 | 0.82 | 0.80 | 0.80 |
| WI | 1.28 | 1.33 | 0.61 | 0.81 | 0.91 | 0.61 | 0.61 |
| WV | 1.61 | 1.60 | 0.27 | 0.22 | 0.25 | 0.26 | 0.27 |
| WY | 1.09 | 1.20 | 0.78 | 0.79 | 0.80 | 0.78 | 0.78 |

*TB = tribal lands

**Scaling factors of 1.00 were applied to tags that had less than 100 tpy emissions assigned in the original source apportionment modeling. Any emissions changes in that state were assigned to a nearby state. For $NO_x$, DC emissions changes were assigned to MD and VT emissions changes were assigned to NY

| Table I-3: Ozone scaling factors for EGU tags in the option 3 scenario | | | | | | | |
|---|---|---|---|---|---|---|---|
| **State Tag** | **2028** | **2030** | **2035** | **2040** | **2045** | **2050** | **2055** |
| AL | 0.92 | 0.97 | 1.02 | 0.87 | 0.71 | 0.73 | 0.73 |
| AR | 1.38 | 0.85 | 0.33 | 0.31 | 0.32 | 0.29 | 0.28 |
| AZ | 0.90 | 0.94 | 1.38 | 1.41 | 1.56 | 1.44 | 1.99 |
| CA | 0.73 | 0.36 | 0.32 | 0.30 | 0.26 | 0.24 | 0.28 |
| CO | 0.90 | 0.50 | 0.30 | 0.17 | 0.16 | 0.15 | 0.15 |
| CT | 0.70 | 0.69 | 0.66 | 0.70 | 0.75 | 0.79 | 0.77 |
| DC | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| DE | 1.36 | 1.36 | 1.38 | 1.80 | 1.92 | 1.96 | 2.06 |
| FL | 0.92 | 0.90 | 0.80 | 0.78 | 0.82 | 0.81 | 0.83 |
| GA | 1.15 | 1.48 | 1.04 | 1.00 | 0.94 | 0.58 | 0.60 |
| IA | 1.27 | 1.29 | 1.08 | 1.06 | 1.04 | 0.63 | 0.63 |
| ID | 1.21 | 1.21 | 1.08 | 1.06 | 0.74 | 0.53 | 0.52 |
| IL | 0.42 | 0.43 | 0.67 | 0.58 | 0.10 | 0.11 | 0.11 |
| IN | 1.13 | 1.12 | 0.81 | 0.66 | 0.56 | 0.21 | 0.22 |
| KS | 1.15 | 0.95 | 0.57 | 0.55 | 0.41 | 0.03 | 0.02 |
| KY | 0.94 | 1.01 | 0.60 | 0.50 | 0.26 | 0.20 | 0.20 |
| LA | 0.79 | 0.82 | 0.67 | 0.56 | 0.52 | 0.37 | 0.43 |
| MA | 1.27 | 1.26 | 1.26 | 1.30 | 1.24 | 1.16 | 1.15 |
| MD | 0.73 | 0.73 | 0.70 | 0.78 | 0.79 | 0.86 | 0.90 |
| ME | 1.67 | 1.20 | 1.23 | 1.21 | 1.21 | 1.19 | 1.19 |
| MI | 0.99 | 0.71 | 0.67 | 0.34 | 0.32 | 0.33 | 0.34 |
| MN | 1.39 | 0.79 | 0.60 | 0.49 | 0.48 | 0.46 | 0.46 |
| MO | 1.34 | 1.06 | 0.99 | 0.80 | 0.58 | 0.53 | 0.52 |
| MS | 0.83 | 0.69 | 0.31 | 0.37 | 0.37 | 0.38 | 0.38 |
| MT | 1.01 | 0.97 | 1.01 | 1.02 | 1.01 | 0.97 | 1.00 |
| NC | 0.50 | 0.35 | 0.20 | 0.16 | 0.13 | 0.07 | 0.07 |
| ND | 1.45 | 1.53 | 0.77 | 0.59 | 0.57 | 0.47 | 0.46 |
| NE | 1.15 | 1.12 | 1.13 | 1.09 | 1.09 | 1.05 | 1.05 |
| NH | 1.13 | 1.17 | 1.11 | 1.13 | 1.13 | 1.16 | 1.16 |
| NJ | 0.97 | 1.00 | 0.96 | 1.02 | 1.04 | 1.09 | 1.17 |
| NM | 0.55 | 0.59 | 0.39 | 0.30 | 0.26 | 0.12 | 0.14 |
| NV | 0.71 | 1.01 | 0.70 | 0.43 | 0.49 | 0.15 | 0.13 |

**Table I-3: Ozone scaling factors for EGU tags in the option 3 scenario**

| State Tag | 2028 | 2030 | 2035 | 2040 | 2045 | 2050 | 2055 |
|---|---|---|---|---|---|---|---|
| NY | 0.91 | 0.78 | 0.71 | 0.51 | 0.52 | 0.54 | 0.54 |
| OH | 0.82 | 0.73 | 0.87 | 0.88 | 0.79 | 0.57 | 0.59 |
| OK | 2.62 | 1.59 | 1.11 | 0.93 | 0.78 | 0.17 | 0.28 |
| OR | 0.37 | 0.10 | 0.08 | 0.00 | 0.00 | 0.00 | 0.00 |
| PA | 0.77 | 0.76 | 0.69 | 0.62 | 0.48 | 0.54 | 0.54 |
| RI | 1.22 | 1.21 | 1.17 | 1.20 | 1.27 | 1.41 | 1.42 |
| SC | 1.28 | 0.96 | 1.36 | 1.21 | 1.30 | 1.51 | 1.44 |
| SD | 0.95 | 1.26 | 1.34 | 0.58 | 0.47 | 0.38 | 0.38 |
| TB | 1.08 | 1.08 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 |
| TN | 2.03 | 0.79 | 0.66 | 0.56 | 0.62 | 0.92 | 0.89 |
| TX | 1.10 | 1.10 | 1.13 | 1.02 | 1.10 | 0.64 | 0.66 |
| UT | 2.39 | 2.28 | 2.25 | 1.49 | 0.24 | 0.31 | 0.30 |
| VA | 1.10 | 0.83 | 0.70 | 0.88 | 0.69 | 0.54 | 0.55 |
| VT | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| WA | 0.73 | 0.83 | 0.91 | 0.76 | 0.81 | 0.78 | 0.79 |
| WI | 1.27 | 1.33 | 0.84 | 0.81 | 0.89 | 0.61 | 0.61 |
| WV | 1.59 | 1.56 | 1.43 | 0.22 | 0.25 | 0.26 | 0.27 |
| WY | 1.11 | 1.20 | 1.23 | 0.79 | 0.80 | 0.78 | 0.78 |

*TB = tribal lands

**Scaling factors of 1.00 were applied to tags that had less than 100 tpy emissions assigned in the original source apportionment modeling. Any emissions changes in that state were assigned to a nearby state. For $NO_x$, DC emissions changes were assigned to MD and VT emissions changes were assigned to NY

**Table I-4: Nitrate scaling factors for EGU tags in the baseline scenario**

| State Tag | 2028 | 2030 | 2035 | 2040 | 2045 | 2050 | 2055 |
|---|---|---|---|---|---|---|---|
| AL | 1.07 | 1.16 | 1.22 | 1.04 | 0.93 | 0.72 | 0.72 |
| AR | 1.83 | 0.96 | 0.38 | 0.30 | 0.30 | 0.26 | 0.24 |
| AZ | 1.02 | 0.93 | 1.03 | 1.06 | 1.29 | 1.16 | 1.46 |
| CA | 0.81 | 0.41 | 0.36 | 0.32 | 0.29 | 0.28 | 0.33 |
| CO | 0.84 | 0.42 | 0.34 | 0.20 | 0.18 | 0.17 | 0.18 |
| CT | 0.66 | 0.64 | 0.60 | 0.60 | 0.63 | 0.65 | 0.65 |
| DC | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| DE | 1.35 | 1.40 | 1.46 | 1.87 | 1.95 | 1.96 | 2.07 |
| FL | 0.97 | 0.95 | 0.84 | 0.82 | 0.85 | 0.81 | 0.85 |
| GA | 1.48 | 1.61 | 1.24 | 1.24 | 0.91 | 0.67 | 0.65 |
| IA | 1.27 | 1.28 | 1.07 | 1.02 | 0.93 | 0.53 | 0.53 |
| ID | 0.99 | 1.13 | 1.25 | 1.46 | 1.08 | 0.74 | 0.69 |
| IL | 0.48 | 0.49 | 0.64 | 0.54 | 0.08 | 0.10 | 0.10 |
| IN | 1.01 | 0.98 | 0.77 | 0.61 | 0.42 | 0.11 | 0.11 |
| KS | 1.88 | 1.44 | 0.79 | 0.54 | 0.45 | 0.04 | 0.03 |
| KY | 1.00 | 0.96 | 0.56 | 0.51 | 0.26 | 0.18 | 0.19 |
| LA | 0.85 | 0.92 | 0.83 | 0.62 | 0.59 | 0.40 | 0.46 |
| MA | 1.26 | 1.26 | 1.24 | 1.25 | 1.21 | 1.10 | 1.09 |
| MD | 0.78 | 0.78 | 0.77 | 0.85 | 0.82 | 0.89 | 0.90 |
| ME | 1.64 | 1.25 | 1.20 | 1.25 | 1.25 | 1.22 | 1.22 |

**Table I-4: Nitrate scaling factors for EGU tags in the baseline scenario**

| State Tag | 2028 | 2030 | 2035 | 2040 | 2045 | 2050 | 2055 |
|---|---|---|---|---|---|---|---|
| MI | 1.10 | 0.75 | 0.71 | 0.31 | 0.31 | 0.31 | 0.32 |
| MN | 1.42 | 0.76 | 0.56 | 0.50 | 0.45 | 0.43 | 0.43 |
| MO | 1.31 | 1.10 | 1.04 | 0.86 | 0.67 | 0.36 | 0.36 |
| MS | 0.86 | 0.83 | 0.50 | 0.45 | 0.46 | 0.42 | 0.40 |
| MT | 1.05 | 1.01 | 1.04 | 1.06 | 1.12 | 1.02 | 1.04 |
| NC | 0.71 | 0.37 | 0.21 | 0.16 | 0.13 | 0.06 | 0.06 |
| ND | 1.47 | 1.45 | 0.71 | 0.51 | 0.44 | 0.40 | 0.40 |
| NE | 1.11 | 1.09 | 1.09 | 1.06 | 0.96 | 0.80 | 0.75 |
| NH | 2.01 | 2.01 | 1.96 | 1.97 | 1.98 | 2.00 | 2.00 |
| NJ | 0.98 | 1.00 | 0.95 | 0.99 | 1.00 | 1.01 | 1.08 |
| NM | 0.56 | 0.63 | 0.34 | 0.28 | 0.30 | 0.16 | 0.16 |
| NV | 0.67 | 0.93 | 0.61 | 0.50 | 0.52 | 0.18 | 0.18 |
| NY | 0.95 | 0.84 | 0.77 | 0.58 | 0.58 | 0.59 | 0.59 |
| OH | 0.84 | 0.74 | 0.86 | 0.84 | 0.80 | 0.40 | 0.41 |
| OK | 3.17 | 1.85 | 1.59 | 1.31 | 0.94 | 0.22 | 0.29 |
| OR | 0.49 | 0.27 | 0.17 | 0.00 | 0.00 | 0.00 | 0.00 |
| PA | 0.87 | 0.87 | 0.77 | 0.62 | 0.54 | 0.59 | 0.60 |
| RI | 1.18 | 1.16 | 1.12 | 1.12 | 1.16 | 1.23 | 1.23 |
| SC | 1.27 | 1.01 | 1.25 | 1.12 | 1.13 | 1.14 | 1.14 |
| SD | 1.11 | 1.25 | 1.31 | 0.48 | 0.43 | 0.18 | 0.18 |
| TB | 0.93 | 0.93 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| TN | 1.38 | 0.79 | 0.54 | 0.44 | 0.47 | 0.64 | 0.58 |
| TX | 1.62 | 1.50 | 1.43 | 1.16 | 1.20 | 0.60 | 0.61 |
| UT | 1.92 | 1.68 | 1.67 | 1.12 | 0.18 | 0.22 | 0.23 |
| VA | 1.25 | 0.85 | 0.78 | 0.91 | 0.73 | 0.62 | 0.62 |
| VT | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| WA | 0.85 | 0.99 | 1.18 | 1.10 | 1.19 | 1.11 | 1.14 |
| WI | 1.45 | 1.50 | 0.89 | 0.83 | 0.77 | 0.52 | 0.52 |
| WV | 1.51 | 1.44 | 1.25 | 0.20 | 0.18 | 0.21 | 0.21 |
| WY | 1.13 | 1.17 | 1.20 | 0.81 | 0.83 | 0.80 | 0.80 |

*TB = tribal lands

**Scaling factors of 1.00 were applied to tags that had less than 100 tpy emissions assigned in the original source apportionment modeling. Any emissions changes in that state were assigned to a nearby state. For $NO_x$, DC emissions changes were assigned to MD and VT emissions changes were assigned to NY

**Table I-5: Nitrate scaling factors for EGU tags in the option 3 scenario**

| State Tag | 2028 | 2030 | 2035 | 2040 | 2045 | 2050 | 2055 |
|---|---|---|---|---|---|---|---|
| AL | 1.08 | 1.18 | 1.22 | 1.05 | 0.93 | 0.72 | 0.72 |
| AR | 1.83 | 0.96 | 0.38 | 0.31 | 0.30 | 0.26 | 0.24 |
| AZ | 1.02 | 0.94 | 1.03 | 1.06 | 1.29 | 1.16 | 1.46 |
| CA | 0.81 | 0.41 | 0.36 | 0.32 | 0.29 | 0.28 | 0.33 |
| CO | 0.84 | 0.42 | 0.34 | 0.20 | 0.18 | 0.17 | 0.18 |
| CT | 0.66 | 0.64 | 0.60 | 0.60 | 0.63 | 0.65 | 0.65 |
| DC | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| DE | 1.34 | 1.36 | 1.45 | 1.82 | 1.93 | 1.95 | 2.06 |

**Table I-5: Nitrate scaling factors for EGU tags in the option 3 scenario**

| State Tag | 2028 | 2030 | 2035 | 2040 | 2045 | 2050 | 2055 |
|---|---|---|---|---|---|---|---|
| FL | 0.96 | 0.94 | 0.84 | 0.82 | 0.85 | 0.81 | 0.85 |
| GA | 1.42 | 1.51 | 1.20 | 1.19 | 0.86 | 0.62 | 0.60 |
| IA | 1.27 | 1.28 | 1.06 | 1.01 | 0.93 | 0.51 | 0.51 |
| ID | 0.99 | 1.13 | 1.25 | 1.46 | 1.08 | 0.74 | 0.69 |
| IL | 0.48 | 0.48 | 0.64 | 0.54 | 0.08 | 0.10 | 0.10 |
| IN | 1.01 | 0.98 | 0.73 | 0.58 | 0.40 | 0.11 | 0.11 |
| KS | 1.90 | 1.39 | 0.79 | 0.61 | 0.44 | 0.04 | 0.03 |
| KY | 1.01 | 0.95 | 0.53 | 0.48 | 0.25 | 0.19 | 0.19 |
| LA | 0.82 | 0.92 | 0.81 | 0.63 | 0.59 | 0.40 | 0.47 |
| MA | 1.26 | 1.26 | 1.24 | 1.25 | 1.21 | 1.10 | 1.10 |
| MD | 0.79 | 0.78 | 0.77 | 0.85 | 0.81 | 0.89 | 0.91 |
| ME | 1.53 | 1.14 | 1.09 | 1.14 | 1.14 | 1.11 | 1.11 |
| MI | 1.09 | 0.75 | 0.70 | 0.31 | 0.31 | 0.31 | 0.32 |
| MN | 1.39 | 0.73 | 0.53 | 0.47 | 0.42 | 0.40 | 0.40 |
| MO | 1.31 | 1.10 | 1.04 | 0.85 | 0.67 | 0.36 | 0.36 |
| MS | 0.86 | 0.79 | 0.50 | 0.45 | 0.46 | 0.42 | 0.40 |
| MT | 1.05 | 1.01 | 1.04 | 1.06 | 1.12 | 1.02 | 1.04 |
| NC | 0.71 | 0.37 | 0.22 | 0.16 | 0.13 | 0.06 | 0.06 |
| ND | 1.47 | 1.46 | 0.77 | 0.51 | 0.45 | 0.40 | 0.40 |
| NE | 1.11 | 1.08 | 1.06 | 1.03 | 0.93 | 0.79 | 0.75 |
| NH | 1.78 | 1.78 | 1.72 | 1.74 | 1.74 | 1.76 | 1.76 |
| NJ | 0.98 | 1.00 | 0.95 | 0.99 | 0.99 | 1.01 | 1.09 |
| NM | 0.56 | 0.62 | 0.35 | 0.28 | 0.30 | 0.16 | 0.16 |
| NV | 0.67 | 0.93 | 0.62 | 0.50 | 0.52 | 0.18 | 0.18 |
| NY | 0.95 | 0.84 | 0.77 | 0.58 | 0.58 | 0.59 | 0.59 |
| OH | 0.84 | 0.73 | 0.82 | 0.83 | 0.63 | 0.36 | 0.37 |
| OK | 3.17 | 1.87 | 1.59 | 1.30 | 0.93 | 0.22 | 0.29 |
| OR | 0.49 | 0.27 | 0.17 | 0.00 | 0.00 | 0.00 | 0.00 |
| PA | 0.86 | 0.86 | 0.77 | 0.62 | 0.53 | 0.59 | 0.60 |
| RI | 1.18 | 1.17 | 1.12 | 1.12 | 1.16 | 1.23 | 1.23 |
| SC | 1.25 | 0.97 | 1.23 | 1.10 | 1.11 | 1.13 | 1.12 |
| SD | 1.11 | 1.25 | 1.31 | 0.50 | 0.45 | 0.25 | 0.26 |
| TB | 0.93 | 0.93 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| TN | 1.39 | 0.67 | 0.54 | 0.43 | 0.47 | 0.64 | 0.58 |
| TX | 1.63 | 1.51 | 1.42 | 1.15 | 1.20 | 0.60 | 0.61 |
| UT | 1.92 | 1.68 | 1.67 | 1.12 | 0.18 | 0.22 | 0.23 |
| VA | 1.25 | 0.86 | 0.78 | 0.91 | 0.73 | 0.62 | 0.62 |
| VT | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| WA | 0.83 | 0.97 | 1.16 | 1.08 | 1.17 | 1.09 | 1.13 |
| WI | 1.45 | 1.48 | 0.89 | 0.83 | 0.76 | 0.52 | 0.52 |
| WV | 1.50 | 1.40 | 1.22 | 0.20 | 0.18 | 0.21 | 0.21 |
| WY | 1.13 | 1.17 | 1.20 | 0.81 | 0.83 | 0.80 | 0.80 |

*TB = tribal lands

**Scaling factors of 1.00 were applied to tags that had less than 100 tpy emissions assigned in the original source apportionment modeling. Any emissions changes in that state were assigned to a nearby state. For $NO_x$, DC emissions changes were assigned to MD and VT emissions changes were assigned to NY

| Table I-6: Sulfate scaling factors for EGU tags in the baseline scenario | | | | | | | |
|---|---|---|---|---|---|---|---|
| **State Tag** | **2028** | **2030** | **2035** | **2040** | **2045** | **2050** | **2055** |
| AL | 1.92 | 1.93 | 2.02 | 2.02 | 2.02 | 2.37 | 1.78 |
| AR | 1.95 | 0.85 | 0.05 | 0.05 | 0.05 | 0.05 | 0.04 |
| AZ | 0.88 | 0.85 | 1.84 | 1.83 | 2.60 | 0.89 | 1.86 |
| CA | 2.42 | 1.56 | 0.42 | 0.40 | 0.49 | 0.49 | 0.50 |
| CO | 0.68 | 0.28 | 0.28 | 0.01 | 0.01 | 0.01 | 0.01 |
| CT | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 |
| DC | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| DE | 0.73 | 0.73 | 0.73 | 0.73 | 0.73 | 0.73 | 0.73 |
| FL | 1.38 | 1.41 | 0.91 | 0.78 | 0.93 | 0.92 | 0.92 |
| GA | 4.40 | 5.05 | 1.14 | 1.14 | 0.79 | 0.00 | 0.00 |
| IA | 1.23 | 1.25 | 1.06 | 1.02 | 0.94 | 0.56 | 0.56 |
| ID | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| IL | 0.33 | 0.32 | 0.39 | 0.32 | 0.01 | 0.00 | 0.00 |
| IN | 1.24 | 1.13 | 0.72 | 0.48 | 0.31 | 0.09 | 0.09 |
| KS | 3.23 | 2.55 | 1.45 | 0.94 | 0.81 | 0.00 | 0.00 |
| KY | 1.15 | 1.17 | 0.40 | 0.37 | 0.15 | 0.07 | 0.08 |
| LA | 0.62 | 0.64 | 0.67 | 0.83 | 0.74 | 0.03 | 0.18 |
| MA | 0.98 | 0.98 | 0.98 | 0.98 | 0.98 | 0.91 | 0.85 |
| MD | 1.99 | 1.73 | 1.79 | 3.98 | 3.27 | 2.83 | 2.83 |
| ME | 1.14 | 0.88 | 0.88 | 0.89 | 0.89 | 0.88 | 0.88 |
| MI | 1.12 | 0.43 | 0.43 | 0.01 | 0.01 | 0.01 | 0.01 |
| MN | 1.28 | 0.53 | 0.47 | 0.47 | 0.39 | 0.38 | 0.38 |
| MO | 1.02 | 0.85 | 0.82 | 0.89 | 0.47 | 0.31 | 0.30 |
| MS | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| MT | 1.36 | 1.15 | 1.20 | 1.20 | 1.37 | 1.15 | 1.20 |
| NC | 0.71 | 0.29 | 0.07 | 0.04 | 0.03 | 0.00 | 0.00 |
| ND | 1.18 | 1.21 | 0.91 | 0.75 | 0.67 | 0.57 | 0.60 |
| NE | 1.05 | 1.05 | 1.05 | 1.04 | 0.97 | 1.01 | 0.95 |
| NH | 4.35 | 4.25 | 2.46 | 2.45 | 2.45 | 2.45 | 2.45 |
| NJ | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| NM | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| NV | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| NY | 0.98 | 0.98 | 0.98 | 0.98 | 0.98 | 0.98 | 0.98 |
| OH | 0.87 | 0.76 | 0.83 | 0.82 | 0.72 | 0.29 | 0.29 |
| OK | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| OR | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| PA | 1.40 | 1.03 | 1.16 | 0.72 | 0.71 | 1.10 | 1.09 |
| RI | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| SC | 1.97 | 1.47 | 1.71 | 1.58 | 1.41 | 1.07 | 1.07 |
| SD | 1.17 | 1.33 | 1.33 | 0.48 | 0.44 | 0.17 | 0.17 |
| TB | 0.98 | 0.98 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| TN | 2.19 | 0.64 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| TX | 3.96 | 3.06 | 2.38 | 2.09 | 2.56 | 1.20 | 1.27 |
| UT | 1.27 | 1.28 | 1.36 | 0.77 | 0.33 | 0.33 | 0.33 |

**Table I-6: Sulfate scaling factors for EGU tags in the baseline scenario**

| State Tag | 2028 | 2030 | 2035 | 2040 | 2045 | 2050 | 2055 |
|---|---|---|---|---|---|---|---|
| VA | 1.22 | 0.93 | 0.88 | 1.10 | 0.98 | 0.80 | 0.80 |
| VT | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| WA | 0.79 | 0.72 | 2.02 | 0.34 | 0.16 | 0.16 | 0.16 |
| WI | 2.92 | 2.98 | 1.78 | 1.70 | 1.63 | 0.61 | 0.61 |
| WV | 1.49 | 1.38 | 1.31 | 0.17 | 0.14 | 0.04 | 0.04 |
| WY | 1.01 | 1.11 | 1.16 | 0.66 | 0.66 | 0.63 | 0.63 |

*TB = tribal lands

**Scaling factors of 1.00 were applied to tags that had less than 100 tpy emissions assigned in the original source apportionment modeling. Any emissions changes in that state were assigned to a nearby state. For $SO_2$, the following emissions change assignments were applied: DC → MD, ID → MT, MS → AL, NV → UT, NM → AZ, OK → TX, OR → WA, RI → CT, VT → NY

**Table I-7: Sulfate scaling factors for EGU tags in the option 3 scenario**

| State Tag | 2028 | 2030 | 2035 | 2040 | 2045 | 2050 | 2055 |
|---|---|---|---|---|---|---|---|
| AL | 1.92 | 1.94 | 2.02 | 2.02 | 2.02 | 2.37 | 1.78 |
| AR | 1.96 | 0.85 | 0.05 | 0.05 | 0.05 | 0.05 | 0.04 |
| AZ | 1.00 | 0.85 | 1.84 | 1.82 | 2.62 | 0.89 | 1.86 |
| CA | 2.42 | 1.56 | 0.42 | 0.40 | 0.49 | 0.49 | 0.50 |
| CO | 0.68 | 0.28 | 0.28 | 0.01 | 0.01 | 0.01 | 0.01 |
| CT | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 |
| DC | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| DE | 0.73 | 0.73 | 0.73 | 0.73 | 0.73 | 0.73 | 0.73 |
| FL | 1.26 | 1.35 | 0.83 | 0.76 | 0.93 | 0.92 | 0.92 |
| GA | 4.26 | 4.73 | 1.14 | 1.14 | 0.79 | 0.00 | 0.00 |
| IA | 1.23 | 1.24 | 1.05 | 1.02 | 0.94 | 0.56 | 0.56 |
| ID | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| IL | 0.33 | 0.32 | 0.39 | 0.31 | 0.01 | 0.00 | 0.00 |
| IN | 1.24 | 1.14 | 0.68 | 0.44 | 0.33 | 0.09 | 0.09 |
| KS | 3.30 | 2.43 | 1.45 | 1.12 | 0.81 | 0.00 | 0.00 |
| KY | 1.20 | 1.15 | 0.40 | 0.34 | 0.13 | 0.08 | 0.08 |
| LA | 0.47 | 0.64 | 0.67 | 0.81 | 0.72 | 0.03 | 0.18 |
| MA | 0.98 | 0.98 | 0.98 | 0.98 | 0.98 | 0.91 | 0.86 |
| MD | 1.99 | 1.73 | 1.79 | 3.98 | 3.27 | 2.83 | 3.07 |
| ME | 1.14 | 0.88 | 0.88 | 0.89 | 0.89 | 0.88 | 0.88 |
| MI | 1.12 | 0.43 | 0.43 | 0.01 | 0.01 | 0.01 | 0.01 |
| MN | 1.28 | 0.53 | 0.47 | 0.47 | 0.39 | 0.38 | 0.38 |
| MO | 1.02 | 0.85 | 0.82 | 0.89 | 0.47 | 0.30 | 0.30 |
| MS | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| MT | 1.36 | 1.15 | 1.20 | 1.20 | 1.37 | 1.15 | 1.20 |
| NC | 0.71 | 0.28 | 0.08 | 0.04 | 0.04 | 0.00 | 0.00 |
| ND | 1.20 | 1.24 | 0.92 | 0.75 | 0.69 | 0.58 | 0.60 |
| NE | 1.05 | 1.05 | 1.04 | 1.03 | 0.95 | 1.01 | 0.95 |
| NH | 3.66 | 3.56 | 2.21 | 2.21 | 2.21 | 2.21 | 2.21 |
| NJ | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| NM | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |

**Table I-7: Sulfate scaling factors for EGU tags in the option 3 scenario**

| State Tag | 2028 | 2030 | 2035 | 2040 | 2045 | 2050 | 2055 |
|---|---|---|---|---|---|---|---|
| NV | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| NY | 0.98 | 0.98 | 0.98 | 0.98 | 0.98 | 0.98 | 0.98 |
| OH | 0.88 | 0.75 | 0.82 | 0.80 | 0.63 | 0.17 | 0.27 |
| OK | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| OR | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| PA | 1.40 | 1.01 | 1.15 | 0.72 | 0.71 | 1.09 | 1.09 |
| RI | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| SC | 1.97 | 1.46 | 1.72 | 1.64 | 1.22 | 1.07 | 1.07 |
| SD | 1.17 | 1.33 | 1.33 | 0.50 | 0.46 | 0.25 | 0.25 |
| TB | 0.98 | 0.98 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| TN | 2.19 | 0.40 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| TX | 3.97 | 3.13 | 2.36 | 2.03 | 2.39 | 1.13 | 1.29 |
| UT | 1.27 | 1.28 | 1.36 | 0.77 | 0.33 | 0.33 | 0.33 |
| VA | 1.22 | 0.94 | 0.88 | 1.10 | 0.98 | 0.80 | 0.80 |
| VT | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| WA | 0.79 | 0.72 | 2.02 | 0.34 | 0.16 | 0.16 | 0.16 |
| WI | 2.91 | 2.93 | 1.78 | 1.70 | 1.60 | 0.61 | 0.61 |
| WV | 1.47 | 1.34 | 1.22 | 0.17 | 0.14 | 0.04 | 0.04 |
| WY | 1.01 | 1.11 | 1.16 | 0.66 | 0.66 | 0.63 | 0.63 |

*TB = tribal lands

**Scaling factors of 1.00 were applied to tags that had less than 100 tpy emissions assigned in the original source apportionment modeling. Any emissions changes in that state were assigned to a nearby state. For $SO_2$, the following emissions change assignments were applied: DC → MD, ID → MT, MS → AL, NV → UT, NM → AZ, OK → TX, OR → WA, RI → CT, VT → NY

**Table I-8: Primary $PM_{2.5}$ scaling factors for EGU tags in the baseline scenario**

| State Tag | 2028 | 2030 | 2035 | 2040 | 2045 | 2050 | 2055 |
|---|---|---|---|---|---|---|---|
| AL | 1.06 | 1.09 | 1.15 | 1.13 | 1.10 | 0.94 | 0.94 |
| AR | 1.61 | 1.04 | 0.89 | 0.70 | 0.69 | 0.62 | 0.61 |
| AZ | 1.09 | 1.02 | 1.29 | 1.35 | 1.64 | 1.83 | 2.27 |
| CA | 0.85 | 0.59 | 0.52 | 0.47 | 0.39 | 0.41 | 0.51 |
| CO | 0.69 | 0.64 | 0.59 | 0.57 | 0.51 | 0.49 | 0.54 |
| CT | 0.70 | 0.68 | 0.54 | 0.56 | 0.63 | 0.78 | 0.77 |
| DC | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| DE | 1.34 | 1.40 | 1.46 | 1.68 | 1.75 | 1.73 | 1.95 |
| FL | 0.97 | 1.00 | 0.96 | 0.97 | 1.04 | 0.93 | 0.95 |
| GA | 0.87 | 0.90 | 0.87 | 0.93 | 0.95 | 0.87 | 0.84 |
| IA | 1.43 | 1.46 | 1.23 | 1.15 | 1.02 | 0.64 | 0.64 |
| ID | 1.80 | 2.15 | 2.45 | 2.84 | 1.98 | 1.15 | 1.04 |
| IL | 0.48 | 0.50 | 0.56 | 0.49 | 0.17 | 0.26 | 0.26 |
| IN | 0.85 | 0.85 | 0.69 | 0.53 | 0.44 | 0.29 | 0.29 |
| KS | 1.15 | 0.84 | 0.25 | 0.19 | 0.16 | 0.08 | 0.06 |
| KY | 0.18 | 0.17 | 0.14 | 0.14 | 0.14 | 0.12 | 0.12 |
| LA | 0.94 | 0.99 | 1.01 | 0.96 | 0.90 | 0.80 | 0.82 |
| MA | 1.08 | 1.07 | 1.00 | 0.97 | 0.91 | 0.82 | 0.82 |

| Table I-8: Primary $PM_{2.5}$ scaling factors for EGU tags in the baseline scenario | | | | | | | |
|---|---|---|---|---|---|---|---|
| **State Tag** | **2028** | **2030** | **2035** | **2040** | **2045** | **2050** | **2055** |
| MD | 0.63 | 0.66 | 0.69 | 0.77 | 0.74 | 0.90 | 0.92 |
| ME | 1.34 | 1.29 | 1.26 | 1.27 | 1.27 | 1.29 | 1.29 |
| MI | 0.89 | 0.68 | 0.69 | 0.49 | 0.51 | 0.57 | 0.60 |
| MN | 1.77 | 0.77 | 0.53 | 0.45 | 0.42 | 0.40 | 0.39 |
| MO | 0.98 | 0.82 | 0.77 | 0.53 | 0.31 | 0.21 | 0.22 |
| MS | 1.13 | 1.18 | 1.15 | 1.03 | 1.03 | 0.92 | 0.86 |
| MT | 0.97 | 0.96 | 0.99 | 1.02 | 1.08 | 0.99 | 0.99 |
| NC | 0.90 | 0.51 | 0.42 | 0.32 | 0.22 | 0.12 | 0.12 |
| ND | 2.01 | 1.93 | 1.21 | 1.02 | 0.88 | 0.81 | 0.81 |
| NE | 0.40 | 0.38 | 0.38 | 0.36 | 0.32 | 0.25 | 0.25 |
| NH | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| NJ | 1.18 | 1.26 | 1.13 | 1.26 | 1.23 | 1.26 | 1.57 |
| NM | 0.84 | 0.89 | 1.08 | 0.98 | 1.10 | 0.60 | 0.64 |
| NV | 0.68 | 0.78 | 0.83 | 0.84 | 0.93 | 0.26 | 0.28 |
| NY | 1.18 | 1.00 | 0.85 | 0.61 | 0.63 | 0.68 | 0.70 |
| OH | 0.77 | 0.74 | 0.88 | 0.95 | 0.95 | 0.69 | 0.70 |
| OK | 1.87 | 1.15 | 1.05 | 0.74 | 0.43 | 0.23 | 0.28 |
| OR | 0.68 | 0.32 | 0.20 | 0.04 | 0.04 | 0.04 | 0.04 |
| PA | 1.14 | 1.14 | 1.18 | 1.11 | 0.96 | 1.03 | 1.05 |
| RI | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| SC | 1.08 | 1.09 | 1.29 | 1.20 | 1.16 | 1.06 | 1.07 |
| SD | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| TB | 1.56 | 1.31 | 0.01 | 0.02 | 0.01 | 0.02 | 0.02 |
| TN | 1.17 | 0.62 | 0.63 | 0.58 | 0.64 | 0.88 | 0.80 |
| TX | 1.48 | 1.48 | 1.63 | 1.33 | 1.41 | 0.92 | 0.91 |
| UT | 1.40 | 1.44 | 1.42 | 1.23 | 1.13 | 1.42 | 1.57 |
| VA | 0.84 | 0.71 | 0.61 | 0.86 | 0.61 | 0.36 | 0.36 |
| VT | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| WA | 1.23 | 1.24 | 1.88 | 1.90 | 1.97 | 1.92 | 1.93 |
| WI | 0.68 | 0.72 | 0.68 | 0.62 | 0.54 | 0.45 | 0.46 |
| WV | 1.67 | 1.55 | 1.36 | 0.45 | 0.39 | 0.61 | 0.63 |
| WY | 1.32 | 1.49 | 1.61 | 1.07 | 1.28 | 1.16 | 1.17 |

*TB = tribal lands

**Scaling factors of 1.00 were applied to tags that had less than 100 tpy emissions assigned in the original source apportionment modeling. Any emissions changes in that state were assigned to a nearby state. For primary $PM_{2.5}$, the following emissions change assignments were applied: DC → MD, NH → ME, RI → CT, SD → ND, VT → NY

| Table I-9: Primary $PM_{2.5}$ scaling factors for EGU tags in the option 3 scenario | | | | | | | |
|---|---|---|---|---|---|---|---|
| **State Tag** | **2028** | **2030** | **2035** | **2040** | **2045** | **2050** | **2055** |
| AL | 1.07 | 1.11 | 1.15 | 1.13 | 1.10 | 0.94 | 0.94 |
| AR | 1.62 | 1.04 | 0.89 | 0.70 | 0.69 | 0.62 | 0.61 |
| AZ | 1.09 | 1.02 | 1.29 | 1.35 | 1.65 | 1.83 | 2.27 |
| CA | 0.85 | 0.59 | 0.52 | 0.47 | 0.39 | 0.41 | 0.51 |
| CO | 0.69 | 0.64 | 0.59 | 0.57 | 0.51 | 0.49 | 0.54 |
| CT | 0.70 | 0.68 | 0.54 | 0.56 | 0.63 | 0.78 | 0.77 |
| DC | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| DE | 1.35 | 1.39 | 1.45 | 1.65 | 1.75 | 1.74 | 1.96 |
| FL | 0.97 | 1.00 | 0.96 | 0.98 | 1.04 | 0.93 | 0.95 |
| GA | 0.87 | 0.90 | 0.87 | 0.93 | 0.95 | 0.87 | 0.84 |
| IA | 1.43 | 1.46 | 1.23 | 1.14 | 1.01 | 0.63 | 0.63 |
| ID | 1.79 | 2.15 | 2.44 | 2.84 | 1.98 | 1.15 | 1.04 |
| IL | 0.48 | 0.50 | 0.56 | 0.49 | 0.17 | 0.26 | 0.26 |
| IN | 0.85 | 0.85 | 0.67 | 0.52 | 0.44 | 0.28 | 0.29 |
| KS | 1.17 | 0.76 | 0.25 | 0.20 | 0.16 | 0.07 | 0.06 |
| KY | 0.18 | 0.17 | 0.14 | 0.14 | 0.15 | 0.13 | 0.12 |
| LA | 0.92 | 0.99 | 1.00 | 0.96 | 0.90 | 0.80 | 0.82 |
| MA | 1.08 | 1.07 | 1.00 | 0.97 | 0.91 | 0.82 | 0.82 |
| MD | 0.64 | 0.68 | 0.69 | 0.77 | 0.74 | 0.90 | 0.93 |
| ME | 1.32 | 1.26 | 1.23 | 1.24 | 1.24 | 1.26 | 1.26 |
| MI | 0.89 | 0.68 | 0.69 | 0.49 | 0.51 | 0.57 | 0.60 |
| MN | 1.76 | 0.76 | 0.53 | 0.45 | 0.42 | 0.39 | 0.40 |
| MO | 0.98 | 0.82 | 0.77 | 0.53 | 0.31 | 0.21 | 0.22 |
| MS | 1.13 | 1.18 | 1.14 | 1.02 | 1.03 | 0.92 | 0.86 |
| MT | 0.97 | 0.96 | 0.99 | 1.02 | 1.08 | 0.99 | 0.99 |
| NC | 0.90 | 0.51 | 0.42 | 0.32 | 0.22 | 0.12 | 0.12 |
| ND | 1.99 | 1.94 | 1.25 | 1.02 | 0.89 | 0.82 | 0.81 |
| NE | 0.40 | 0.38 | 0.35 | 0.34 | 0.30 | 0.25 | 0.25 |
| NH | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| NJ | 1.18 | 1.26 | 1.13 | 1.25 | 1.21 | 1.25 | 1.58 |
| NM | 0.84 | 0.89 | 1.08 | 0.98 | 1.10 | 0.60 | 0.64 |
| NV | 0.68 | 0.78 | 0.83 | 0.84 | 0.93 | 0.26 | 0.28 |
| NY | 1.18 | 1.00 | 0.85 | 0.61 | 0.63 | 0.68 | 0.70 |
| OH | 0.77 | 0.74 | 0.87 | 0.94 | 0.83 | 0.67 | 0.68 |
| OK | 1.87 | 1.15 | 1.05 | 0.74 | 0.43 | 0.23 | 0.28 |
| OR | 0.67 | 0.32 | 0.20 | 0.04 | 0.04 | 0.04 | 0.04 |
| PA | 1.14 | 1.13 | 1.18 | 1.11 | 0.95 | 1.03 | 1.05 |
| RI | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| SC | 1.08 | 1.08 | 1.29 | 1.20 | 1.16 | 1.07 | 1.07 |
| SD | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |

**Table I-9: Primary $PM_{2.5}$ scaling factors for EGU tags in the option 3 scenario**

| State Tag | 2028 | 2030 | 2035 | 2040 | 2045 | 2050 | 2055 |
|---|---|---|---|---|---|---|---|
| TB | 1.56 | 1.31 | 0.01 | 0.02 | 0.01 | 0.02 | 0.02 |
| TN | 1.17 | 0.59 | 0.63 | 0.58 | 0.63 | 0.88 | 0.80 |
| TX | 1.48 | 1.49 | 1.62 | 1.32 | 1.38 | 0.91 | 0.91 |
| UT | 1.40 | 1.44 | 1.41 | 1.23 | 1.13 | 1.42 | 1.57 |
| VA | 0.84 | 0.72 | 0.60 | 0.86 | 0.61 | 0.36 | 0.36 |
| VT | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| WA | 1.23 | 1.24 | 1.88 | 1.90 | 1.97 | 1.92 | 1.93 |
| WI | 0.68 | 0.72 | 0.68 | 0.62 | 0.54 | 0.45 | 0.46 |
| WV | 1.66 | 1.51 | 1.35 | 0.45 | 0.39 | 0.61 | 0.62 |
| WY | 1.34 | 1.49 | 1.61 | 1.07 | 1.27 | 1.16 | 1.17 |

*TB = tribal lands

**Scaling factors of 1.00 were applied to tags that had less than 100 tpy emissions assigned in the original source apportionment modeling. Any emissions changes in that state were assigned to a nearby state. For primary $PM_{2.5}$, the following emissions change assignments were applied: DC → MD, NH → ME, RI → CT, SD → ND, VT → NY

## I.4 Air Quality Surface Results

The spatial fields of baseline AS-MO3 and Annual Average $PM_{2.5}$ in 2028 are presented in Figure I-6 and I-7, respectively. It is important to recognize that ozone is a secondary pollutant, meaning that it is formed through chemical reactions of precursor emissions in the atmosphere. As a result of the time necessary for precursors to mix in the atmosphere and for these reactions to occur, ozone can either be highest at the location of the precursor emissions or peak at some distance downwind of those emissions sources. The spatial gradients of ozone depend on a multitude of factors including the spatial patterns of NOx and VOC emissions and the meteorological conditions on a particular day. Thus, on any individual day, high ozone concentrations may be found in narrow plumes downwind of specific point sources, may appear as urban outflow with large concentrations downwind of urban source locations or may have a more regional signal. However, in general, because the AS-MO3 metric is based on the average of concentrations over more than 180 days in the spring and summer, the resulting spatial fields are rather smooth without sharp gradients, compared to what might be expected when looking at the spatial patterns of MDA8 ozone concentrations on specific high ozone episode days. $PM_{2.5}$ is made up of both primary and secondary components. Secondary $PM_{2.5}$ species sulfate and nitrate often demonstrate regional signals without large local gradients while primary $PM_{2.5}$ components often have heterogenous spatial patterns with larger gradients near emissions sources. Both secondary and primary $PM_{2.5}$ contribute to the spatial patterns shown in Figure I-7 as demonstrated by the extensive areas of elevated concentrations over much of the Eastern US which have large secondary components and hotspots in urban areas which are impacted by primary PM emissions.

Figure I-6 through Figure I-13 present the model-predicted changes in the AS-MO3 between the baseline and Option 3 for 2028, 2030, 2035, 2040, 2045, and 2050 calculated as Option 3 minus the baseline. Figures I-14 to I-19 present the model-predicted changes in annual average $PM_{2.5}$ between the baseline and Option 3 for 2028, 2030, 2035, 2040, 2045, and 2050 calculated as Option 3 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. While $SO_2$, $NO_x$ and primary $PM_{2.5}$ emissions changes all contributed to the $PM_{2.5}$ changes depicted in Figures I-14 through I-19, the $PM_{2.5}$ component species with the larger changes was sulfate and consequently the $SO_2$ emissions changes have the largest impact on predicted changes in $PM_{2.5}$ concentrations through sulfate, ammonium and particle-bound water impacts. The spatial fields used to create these maps serve as an input to the benefits analysis.

**Figure I-6: Map of AS-MO3 in the 2028 Baseline**

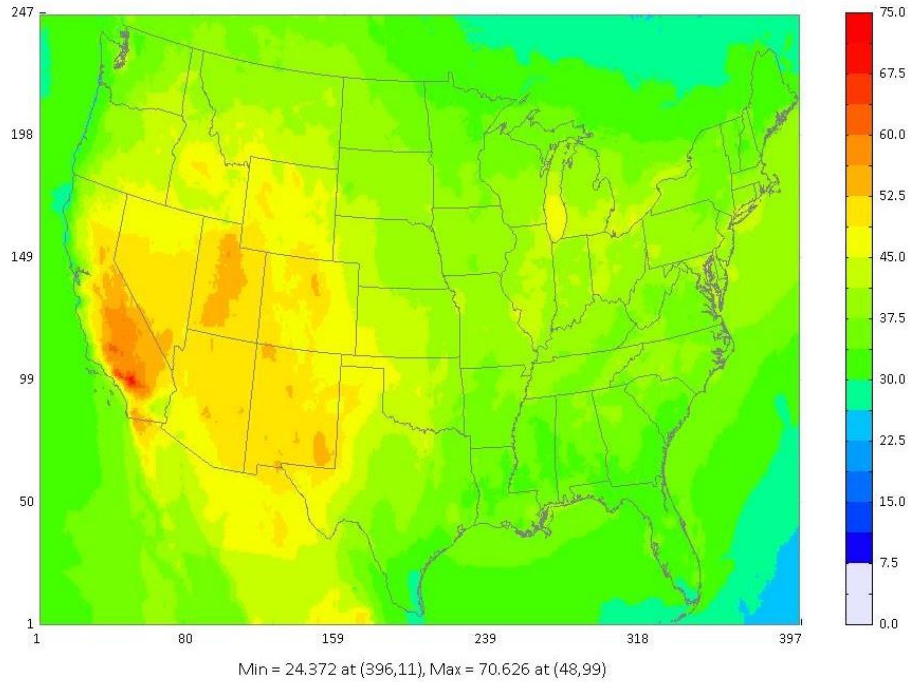



**Figure I-7: Map of Annual Average $PM_{2.5}$ in the 2028 Baseline**

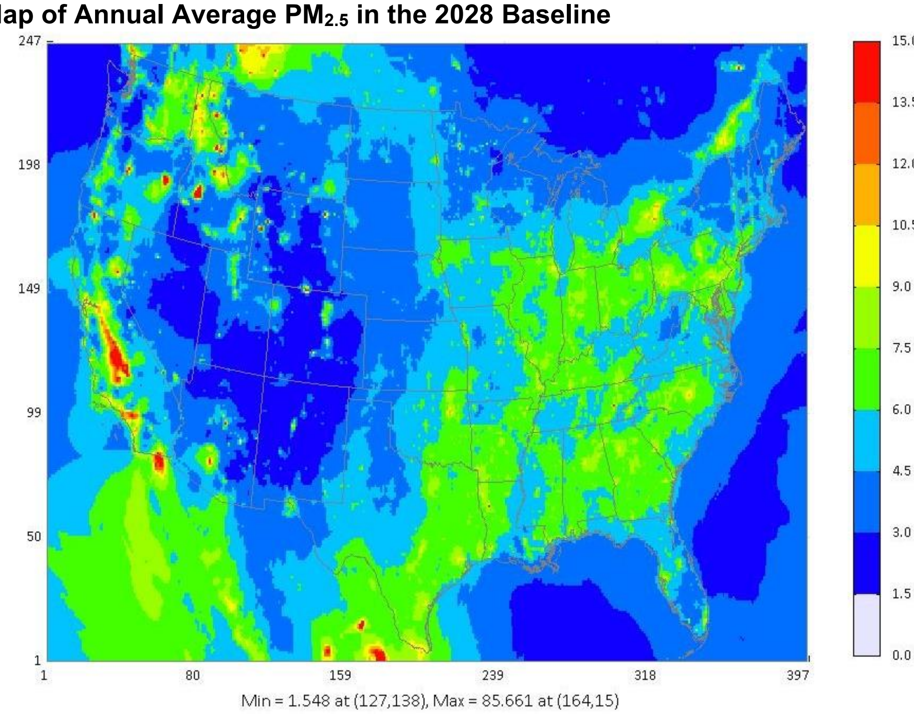


**Figure I-8: Map of Change in Apr-September MDA8 Ozone (ppb): 2028 Option 3 – Baseline**

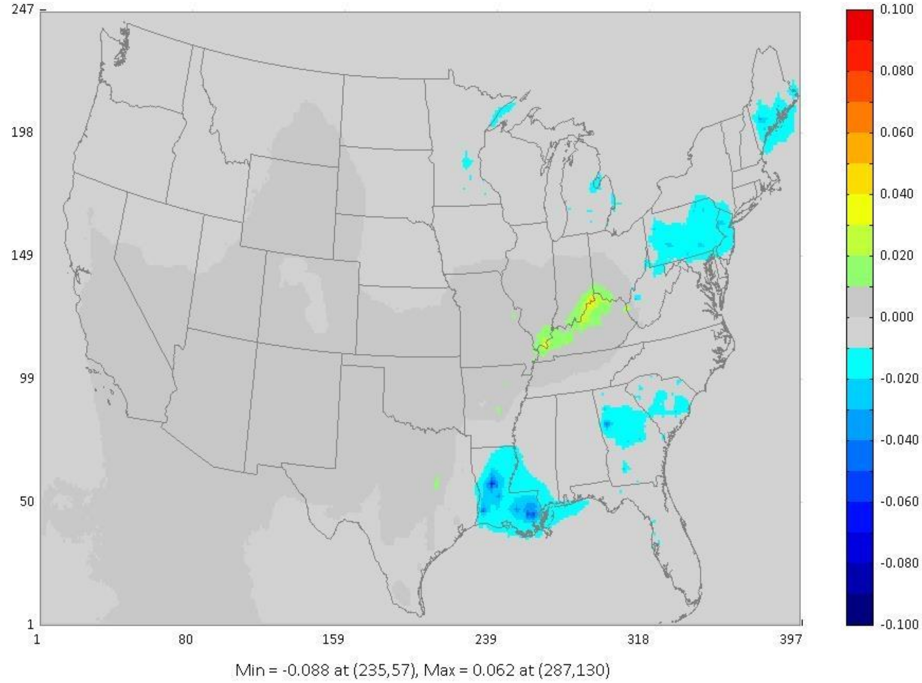



**Figure I-9: Map of Change in Apr-September MDA8 Ozone (ppb): 2030 Option 3 – Baseline**

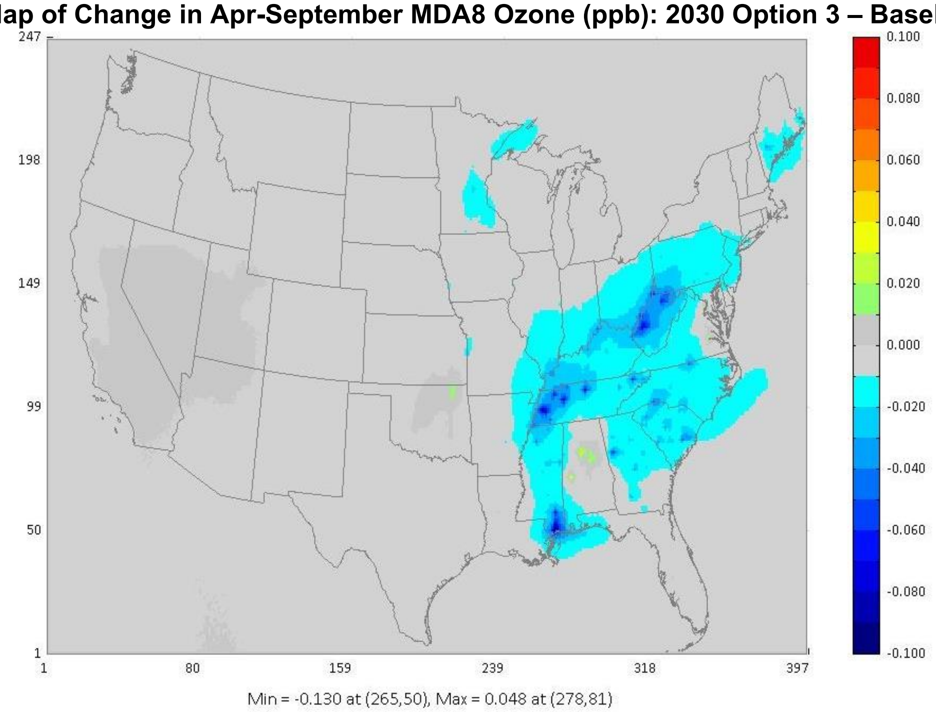


**Figure I-10: Map of Change in Apr-September MDA8 Ozone (ppb): 2035 Option 3 – Baseline**

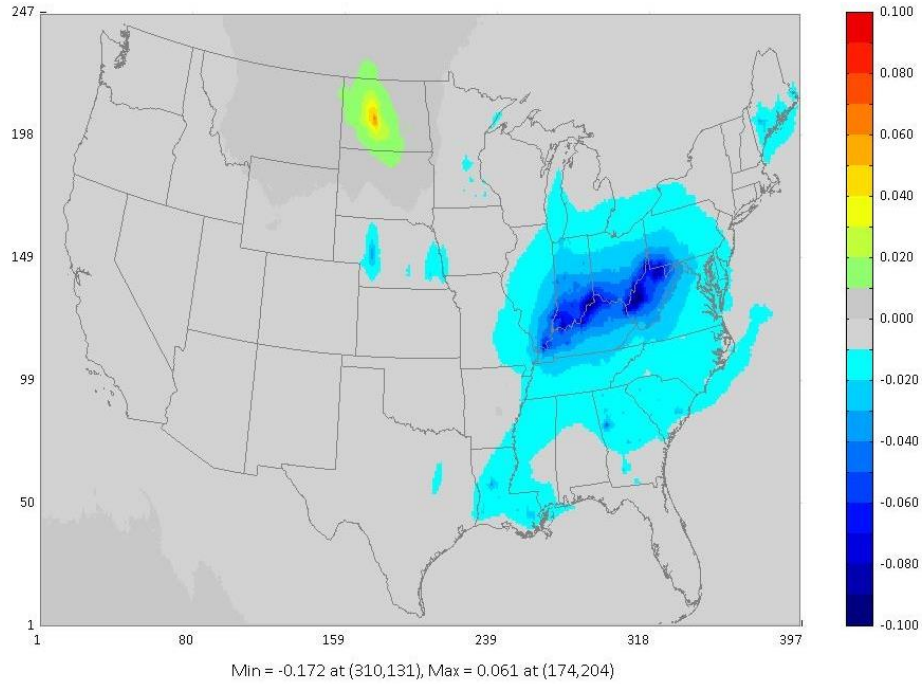



**Figure I-11: Map of Change in Apr-September MDA8 Ozone (ppb): 2040 Option 3 – Baseline**

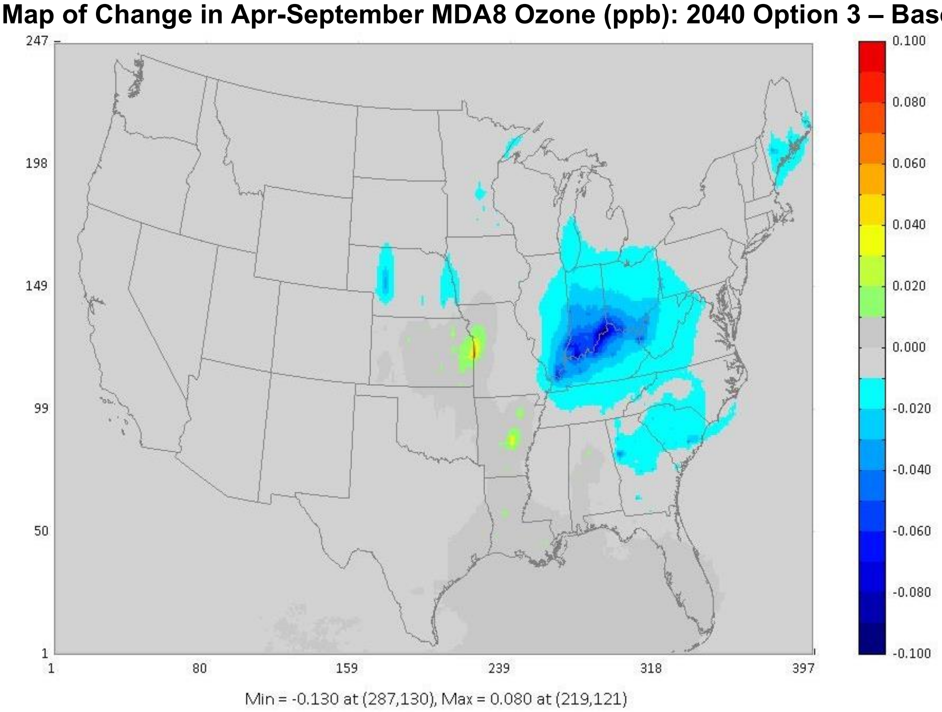


**Figure I-12: Map of Change in Apr-September MDA8 Ozone (ppb): 2045 Option 3 – Baseline**

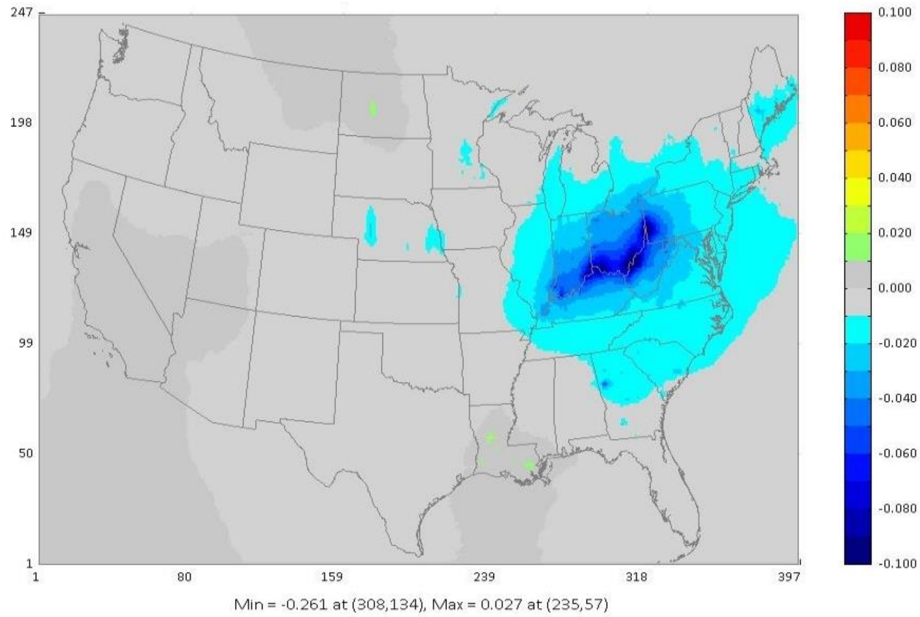



**Figure I-13: Map of Change in Apr-September MDA8 Ozone (ppb): 2050 Option 3 – Baseline**

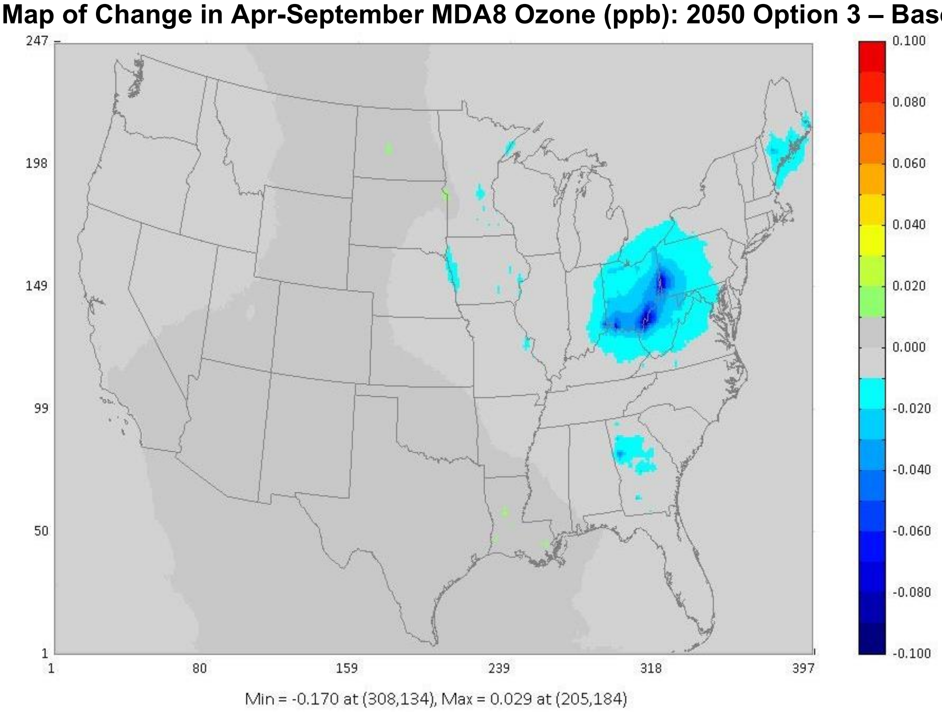


**Figure I-14: Map of Change in Annual Mean $PM_{2.5}$ ($\mu g/m^3$): 2028 Option 3 – Baseline**

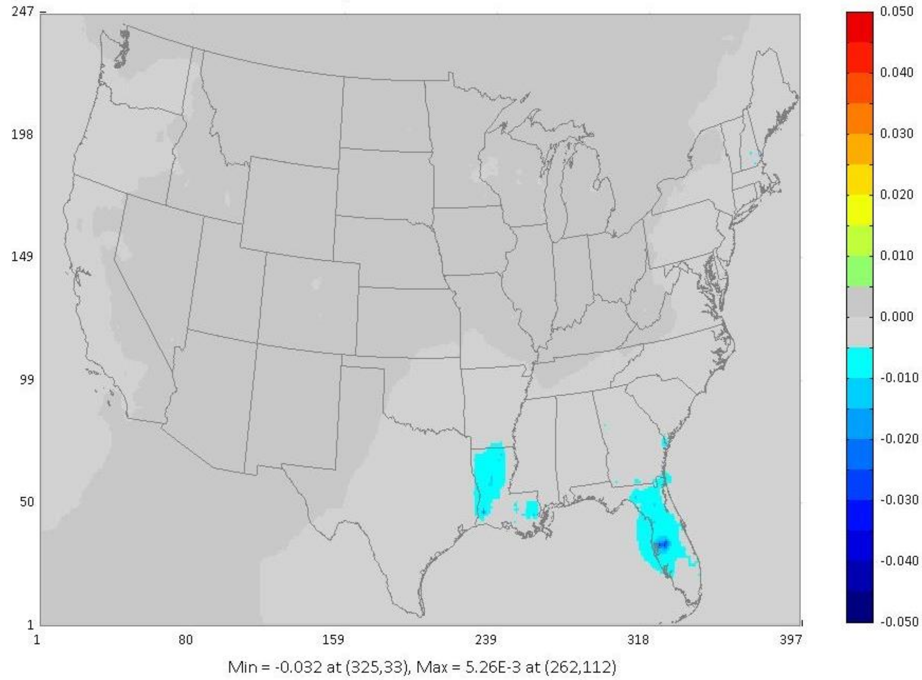



**Figure I-15: Map of Change in Annual Mean $PM_{2.5}$ ($\mu g/m^3$): 2030 Option 3 – Baseline**

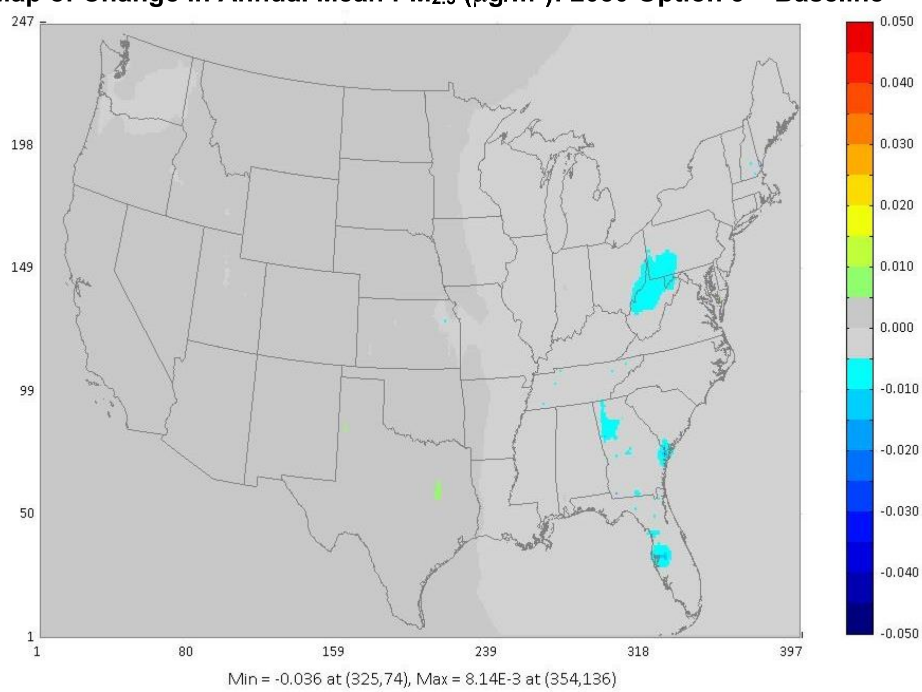


**Figure I-16: Map of Change in Annual Mean $PM_{2.5}$ ($\mu g/m^3$): 2035 Option 3 – Baseline**

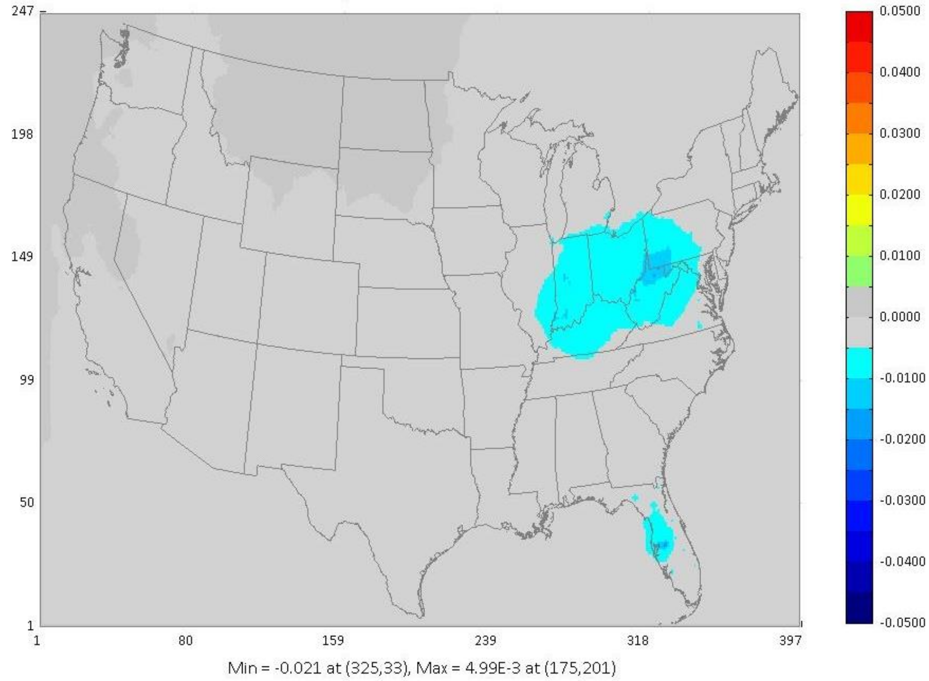



**Figure I-17: Map of Change in Annual Mean $PM_{2.5}$ ($\mu g/m^3$): 2040 Option 3 – Baseline**

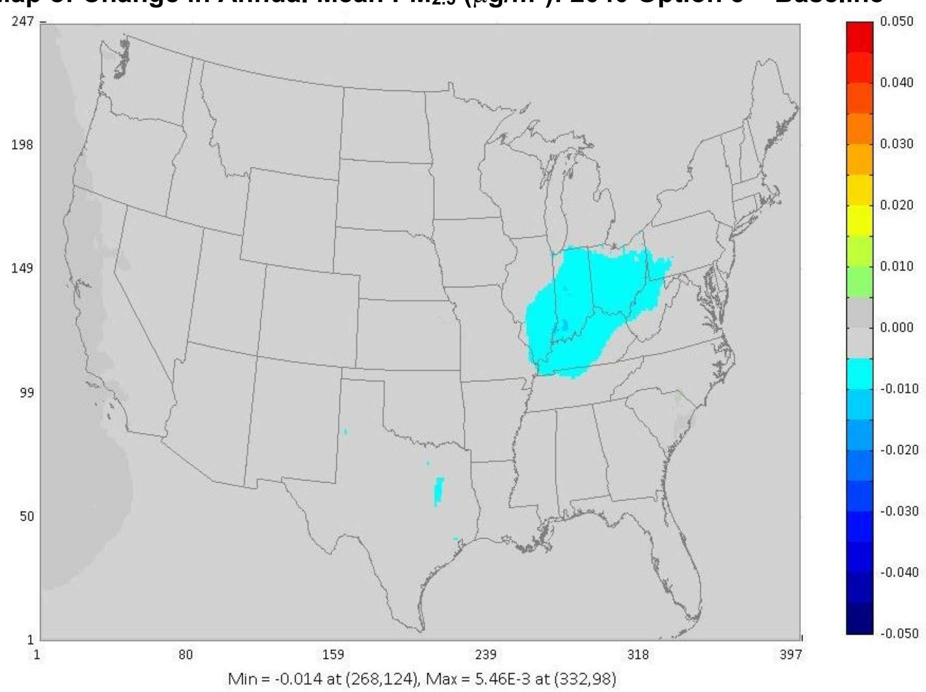


**Figure I-18: Map of Change in Annual Mean $PM_{2.5}$ ($\mu g/m^3$): 2045 Option 3 – Baseline**

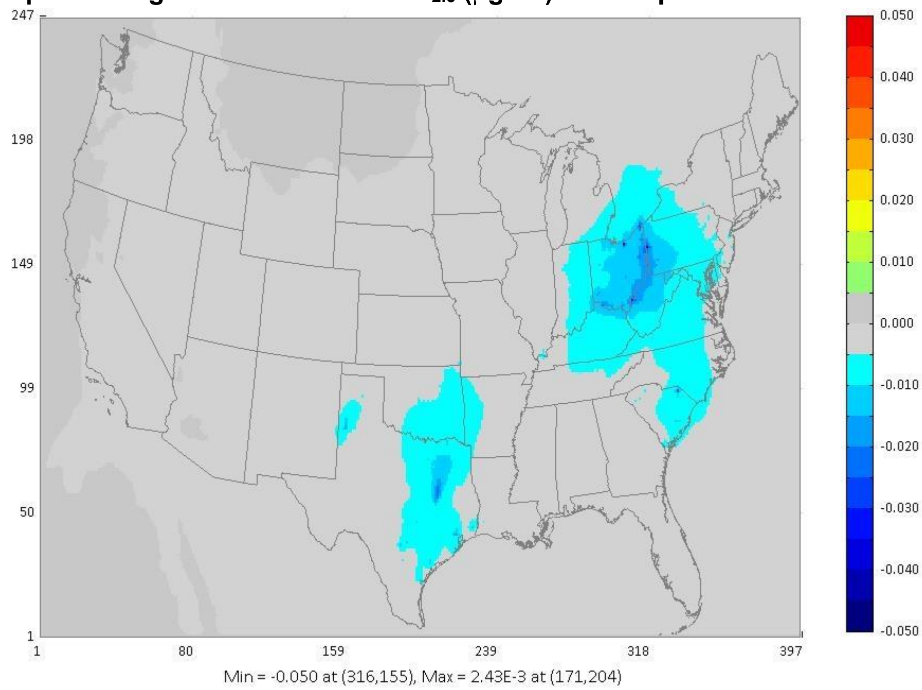
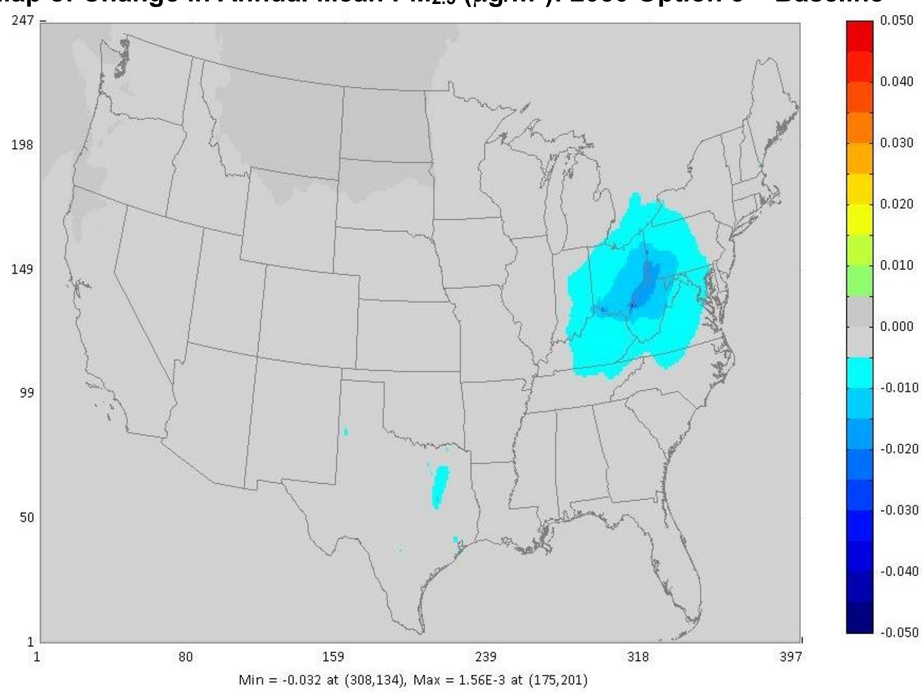



**Figure I-19: Map of Change in Annual Mean $PM_{2.5}$ ($\mu g/m^3$): 2050 Option 3 – Baseline**




## J.5 Uncertainties and Limitations of the Air Quality Methodology

One limitation of the scaling methodology for creating ozone and $PM_{2.5}$ surfaces associated with the baseline or Option 3 scenarios described above is that the methodology 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. The method applied in this analysis is consistent with how air quality estimations have been made in several prior regulatory analyses (U.S. EPA, 2012, 2019h, 2020d). We note that air quality is calculated in the same manner for the baseline and for Option 3, so any uncertainties associated with these assumptions is propagated through results for both the baseline and Option 3 scenarios in the same manner. In addition, emissions changes between baseline and Option 3 are relatively small compared to modeled 2026 emissions that form the basis of the source apportionment approach described in this appendix. 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). A second limitation is that the source apportionment contributions are informed by the spatial and temporal distribution of the emissions from each source tag as they occur in the 2026 modeled case. Thus, the contribution modeling results do not allow us to consider the effects of any changes to spatial distribution of EGU emissions within a state between the 2026 modeled case and the baseline and Option 3 scenarios analyzed in this RIA. Finally, the 2026 CAMx-modeled concentrations themselves have some uncertainty. While all models have some level of inherent uncertainty in their formulation and inputs, the base-year 2016 model outputs have been evaluated against ambient measurements and have been shown to adequately reproduce spatially and temporally varying concentrations (U.S. EPA, 2022a, 2022b).