United States
Environmental Protection
Agency

Office of Water
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Benefit and Cost Analysis for the Effluent Limitations Guidelines and Standards for the Steam Electric Power Generating Point Source Category

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September 2015

U.S. Environmental Protection Agency
Office of Water (4303T)
Engineering and Analysis Division
1200 Pennsylvania Avenue, NW
Washington, DC 20460

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List of Abbreviations

ADD	Average daily dose
ASMFC	Atlantic States Marine Fisheries Commission
As	Arsenic
AFSC	Alaskan Fisheries Science Center
AWQC	Ambient water quality criteria
BAT	Best available technology economically achievable
BCA	Benefit cost analysis
BEA	Bureau of Economic Analysis
BenMAP	Environmental Benefits Mapping and Analysis Program
BLS	Bureau of Labor Services
BOD	Biochemical oxygen demand
BPJ	Best professional judgment
BPT	Best practicable control technology currently available
C&D	Construction and development
Cal OEHHA	California Office of Environmental Health Hazard Assessment
CBG	Census Block Group
CBI	Confidential Business Information
CCI	Construction Cost Index
CCME	Canadian Council of Ministers of the Environment
CCR	Coal combustion residuals
CMAQ	Community Multiscale Air Quality
CO_2	Carbon dioxide
COD	Chemical oxygen demand
COI	Cost of illness
COPD	Chronic obstructive pulmonary disease
CPI	Consumer Price Index
CSF	Cancer slope factor
CVD	Cardiovascular disease
DCN	Document Control Number
DHHS	Department of Health and Human Services
DO	Dissolved oxygen
DOJ	Department of Justice
EA	Environmental Assessment
ECI	Employment Cost Index
EGU	Electric Generating Unit
EJ	Environmental justice
ELGs	Effluent limitations guidelines and standards
EPA	United States Environmental Protection Agency
ESA	Endangered Species Act
FC	Fecal coliform
FCA	Fish consumption advisories
FGD	Flue gas desulfurization
FGMC	Flue gas mercury control
FR	Federal Register
GDP	Gross domestic product
GIS	Geographic Information System

Hg	Mercury
HR	Hazard ratio
HUC	Hydrologic unit code
IEUBK	Integrated Exposure, Uptake, and Biokinetics
IPM	Integrated Planning Model
IRIS	Integrated Risk Information System
IQ	Intelligence quotient
LADD	Lifetime average daily dose
MCL	Maximum contaminant level
MCLG	Maximum contaminant level goal
MDNR	Minnesota Department of Natural Resources
MEPS	Medical Expenditure Panel Survey
NAAQS	National Ambient Air Quality Standards
NEFSC	Northeast Fisheries Science Center
NERC	North American Electric Reliability Corporation
NESHAP	National Emissions Standards for Hazardous Air Pollutants
NHD	National hydrography dataset
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
NO_X	Nitrogen oxides
NPDES	National Pollutant Discharge Elimination System
NRC	National Research Council
NRD	Natural resource damages
NSPS	New Source Performance Standards
NWIS	National Water Information System
OAQPS	Office of Air Quality Planning and Standards
O&M	Operation and maintenance
OMB	Office of Management and Budget
OPPT	Office of Pollution Prevention and Toxics
ORCR	Office of Resource Conservation and Recovery
OSC	On-scene coordinator
PbB	Blood lead concentration
PIFSC	Pacific Islands Fisheries Science Center
ppm	parts per million
PSES	Pretreatment Standards for Existing Sources
PSNS	Pretreatment Standards for New Sources
QA	Quality assurance
QC	Quality control
RIA	Regulatory Impact Analysis
RSEI	Risk-Screening Environmental Indicators
SCC	Social cost of carbon
Se	Selenium
SEFSC	Southeast Fisheries Science Center
SO_2	Sulfur dioxide
SPARROW	SPAtially Referenced Regressions On Watershed attributes
STORET	STOrage and RETrieval Data Warehouse
SWFSC	Southwest Fisheries Science Center
T&E	Threatened and endangered

TDD	Technical Development Document
TDS	Total dissolved solids
THMs	Trihalomethanes
TN	Total nitrogen
TP	Total phosphorus
TRI	Toxic Release Inventory
TSD	Technical Support Document
TSS	Total suspended solids
TVA	Tennessee Valley Authority
U.S. FWS	United States Fish and Wildlife Service
USGS	United States Geological Survey
VSL	Value of a statistical life
WQI	Water quality index
WQL	Water quality ladder
WTP	Willingness to pay

1 Introduction

The U.S. Environmental Protection Agency (EPA) is promulgating a regulation that would strengthen the existing controls on discharges from steam electric power plants by revising technology-based effluent limitations guidelines and standards (ELGs) for the steam electric power generating point source category, 40 CFR part 423.

The analyses supporting the final ELGs for the Steam Electric Power Generating Point Source Category 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.

This document presents an analysis of the social benefits and social costs of the final rule and complements other analyses EPA conducted in support of the ELGs, described in separate documents:

- *Environmental Assessment for the Effluent Limitations Guidelines and Standards for the Steam Electric Power Generating Point Source Category (EA)* (U.S. EPA, 2015a; DCN SE04527). The EA summarizes the environmental and human health improvements that are expected to result from implementation of the ELGs.
- *Technical Development Document for the Effluent Limitations Guidelines and Standards for the Steam Electric Power Generating Point Source Category (TDD)* (U.S. EPA, 2015b; DCN SE05904). The TDD provides background on the final ELGs; applicability and summary of the ELGs; industry description; wastewater characterization and identification of pollutants of concern; and treatment technologies and pollution prevention techniques. It also documents EPA's engineering analyses to support the final rule including facility specific compliance cost estimates, pollutant loadings, and non-water quality impact assessment.
- *Regulatory Impact Analysis for the Effluent Limitations Guidelines and Standards for the Steam Electric Power Generating Point Source Category (RIA)* (U.S. EPA, 2015c; DCN SE05976). The RIA describes EPA's analysis of the costs and economic impacts of the final rule. This analysis provides the basis for social cost estimates presented in this document. The RIA also provides information pertinent to meeting several legislative and administrative requirements, including the Regulatory Flexibility Act of 1980 (as amended by the Small Business Regulatory Enforcement Fairness Act (SBREFA) of 1996), the Unfunded Mandates Reform Act of 1995, Executive Order 13211 on Actions Concerning Regulations That Significantly Affect Energy Supply, Distribution, or Use, and others.

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

1.1 Steam Electric Power Plants

The final rule establishes new limitations and standards for plants subject to the previously established ELGs for the Steam Electric Power Generating Point Source Category The ELGs apply to a subset of the electric power industry, namely those plants with discharges resulting from the operation of a generating unit "primarily engaged in the generation of electricity for distribution and/or sale, which results primarily from a process utilizing fossil-type fuels (coal, petroleum coke, oil, gas) or nuclear fuel in conjunction with a thermal cycle employing the steam water system as the thermodynamic medium."[1]

Based on data EPA obtained from the 2010 Questionnaire for the Steam Electric Power Generating Effluent Guidelines (industry survey; U.S. EPA, 2010c) and other sources (see *TDD*), EPA estimates that there were 1,080 steam electric power plants in 2009.[2] EPA projects that a subset of these plants will implement changes to meet the final limitations (refer to the *TDD* and *RIA* for details).

1.2 Regulatory Options Analyzed for the Final ELGs

EPA presents six regulatory options for the final rule (see *Table 1-1*). These options differ in the wastestreams controlled by the regulation, the size of the units controlled, and the stringency of controls (see *TDD* for a detailed discussion of the options and the associated treatment technology bases). Thus, EPA evaluated revising or establishing Best Available Technology Economically Achievable (BAT), New Source Performance Standards (NSPS), Pretreatment Standards for Existing Sources (PSES), and Pretreatment Standards for New Sources (PSNS) that apply to discharges of up to seven wastestreams: FGD wastewater, fly ash transport water, bottom ash transport water, combustion residual leachate from landfills and surface impoundments, wastewater from FGMC systems, wastewater from gasification systems, and nonchemical metal cleaning wastes.

EPA is establishing limitations and standards for existing sources (BAT/PSES) based on the technologies in Option D. For new sources, EPA selected the technologies in Option F as the basis for the NSPS and PSNS. The preamble that accompanies the final rule explains the rationale for EPA's decision.

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[1] The final rule contains three minor modifications to the wording of the previously established applicability provision in the steam electric power generating ELGs to reflect EPA's longstanding interpretation and implementation of the rule. These revisions do not alter the universe of generating units regulated by the ELGs, nor do they impose compliance costs on the industry. Instead, they remove potential ambiguity in the regulations by revising the text to more clearly reflect EPA's longstanding interpretation. See Section VIII of the preamble for more details.

[2] The industry survey EPA conducted in 2010 requested data for several years of operation, up to the most recent complete calendar year at the time the survey was conducted: 2009.

Table 1-1: Steam Electric ELG Regulatory Options

Wastestreams	Technology Basis for BAT/NSPS/PSES/PSNS Regulatory Options					
	A	**B**	**C**	**D**	**E**	**F**
FGD Wastewater	Chemical Precipitation	Chemical Precipitation + Biological Treatment	Chemical Precipitation + Biological Treatment	Chemical Precipitation + Biological Treatment	Chemical Precipitation + Biological Treatment	Evaporation
Fly Ash Transport Water	Dry Handling	Dry Handling	Dry Handling	Dry Handling	Dry Handling	Dry handling
Bottom Ash Transport Water	Impoundment (Equal to BPT)	Impoundment (Equal to BPT)	Dry handling / Closed loop (for units >400 MW); Impoundment (Equal to BPT)(for units ≤400 MW)	Dry Handling / Closed loop	Dry Handling / Closed loop	Dry handling / Closed loop
FGMC Wastewater	Dry Handling	Dry Handling	Dry Handling	Dry Handling	Dry Handling	Dry handling
Gasification Wastewater	Evaporation	Evaporation	Evaporation	Evaporation	Evaporation	Evaporation
Combustion Residual Leachate	Impoundment (Equal to BPT)	Impoundment (Equal to BPT)	Impoundment (Equal to BPT)	Impoundment (Equal to BPT)	Chemical Precipitation	Chemical Precipitation
Nonchemical Metal Cleaning Wastes	[Reserved]	[Reserved]	[Reserved]	[Reserved]	[Reserved]	[Reserved]

Source: U.S. EPA, 2015

In the remainder of this document, EPA presents the analytical results only for Options A through E for existing sources. During development of the final rule, EPA decided not to base the final rule on Option F for existing sources due primarily to the high cost of that option, particularly in light of the costs associated with other rulemakings expected to impact the steam electric industry (see Section VIII.C.1 of the preamble). As a result, EPA chose not to conduct particular analyses for Option F to the same extent that it did for some of the other options considered.

While EPA calculated the cost impacts of New Sources Performance Standards (NSPS) and Pretreatment Standards for New Sources (PSNS) for the final ELGs, no new coal steam plants have been announced nor are projected (see RIA Section 3.2; U.S. EPA 2015c). The lack of any new coal steam plant in the near future and the site-specific nature of environmental effects and benefits make the assessment of load reductions and benefits associated with new source requirements hypothetical and speculative. Accordingly, EPA focused the analysis of the benefits of the final ELGs on the BAT/PSES requirements for existing sources.

1.3 Analysis Scenarios

EPA made every effort to appropriately account for other rules in its many analyses for this rule. Since proposal, EPA has promulgated several other rules affecting the steam electric industry: the Cooling Water Intake Structures (CWIS) rule for existing facilities (79 FR 48300), the CCR rule (80 FR 21302), the CPP rule (FR publication forthcoming). At the time it conducted these analyses, the CPP rule had not yet been finalized, and thus EPA used the proposed CPP rule for its analyses as a proxy for the final CPP rule requirements. In some cases, EPA performed two sets of parallel analyses to demonstrate how the other rules affected the final ELGs. For example, EPA conducted an assessment of the final ELGs both with and without accounting for the CPP rule. EPA approached analyses associated with each rulemaking carefully. EPA also recognizes that the steam electric industry complying with three regulations cumulatively in a very short period time may choose different compliance path than assumed in the analyses. The cumulative effect introduces uncertainty on the compliance path, and thereby on the benefits and costs associated with these rules.

The results presented in the main body of this document are based on this scenario with the CPP rule. The results of EPA's analyses without accounting for the CPP rule are presented in *Appendix B*.

1.4 Loading and Withdrawal Reductions

1.4.1 Loading Reductions

EPA expects that final rule will reduce discharge loads of various categories of pollutants including conventional (such as total suspended solids (TSS), biochemical oxygen demand (BOD), and oil and grease), priority (such as mercury (Hg), arsenic (As), and selenium (Se)), and non-conventional pollutants (such as phosphorus (TP), chemical oxygen demand (COD) and total dissolved solids (TDS)). *Table 1-2* summarizes the estimated pollutant reductions under each of the five regulatory options for existing sources.

Table 1-2: Pollutant Removal for Final ELGs Regulatory Options

Regulatory Option	Pollutant Load Reduction (pounds per year)
Option A	123,814,202
Option B	132,342,281
Option C	306,198,515
Option D	371,152,958
Option E	382,032,630

Source: U.S. EPA Analysis, 2015

1.4.2 Water Withdrawal Reductions

The regulatory options are also expected to eliminate or reduce water withdrawals associated with wet ash transport and wet FGD scrubbers. EPA estimates that the final BAT/PSES option (Option D) will reduce surface water withdrawals at steam electric power plants by 57 billion gallons per year (155 million gallons per day), and reduce withdrawals of 8 million gallons of groundwater per year (21,971 gallons per day).

1.4.3 Loading Reductions Used in Estimating Benefits

EPA revised the estimated steam electric power generating plant discharge loads to incorporate data submitted via public comments and following additional review conducted after completing the benefit analyses described in this report.[3] The revisions affect baseline loadings as well as loading reductions

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[3] EPA reevaluated the bottom ash dataset for the final rule, including the addition of new data submitted via public comments. EPA subjected all data to its revised data editing criteria and as such, removed or replaced some of the data included in the 1982 TDD. See *TDD* for details (U.S. EPA, 2015b).

estimated for each of the regulatory options. The load reductions presented in *Table 1-2* above reflect these revisions.

Table 1-3 shows loading reductions calculated from the original loading data used in estimating the benefits of the regulatory options; these are 0.01 percent to 0.17 percent greater than the reductions shown *Table 1-2*. The changes affect most pollutants of concern, including arsenic, cadmium, chromium, lead, mercury, nickel, total nitrogen, total phosphorus, selenium, total suspended solids, and zinc. See *TDD* for details (U.S. EPA, 2015b).

Table 1-3: Pollutant Removal for Final ELGs Regulatory Options Used in Estimating Benefits

Regulatory Option	Pollutant Load Reduction (pounds per year)
Option A	124,030,659
Option B	132,558,737
Option C	306,236,745
Option D	371,220,336
Option E	382,110,008

Source: U.S. EPA Analysis, 2015

Revisions to the plant loadings may affect estimated benefits in several categories. Implication of the changes are summarized in Table 1-4, and discussed at greater length in each of the relevant chapters.

Table 1-4: Impacts of Loading Reduction Revisions on Benefit Estimates

Benefit Category	Impact of Revised Loading Reduction on Benefit Estimate	Report Chapter
Human health benefits (from fish consumption)	Revisions may reduce benefits, relative to estimates presented in Chapter 3.	3
Nonmarket benefits from water quality improvements	Revisions may reduce benefits, relative to estimates presented in Chapter 4.	4
Benefits to threatened and endangered species	Revisions may reduce benefits, relative to estimates presented in Chapter 5.	5
Benefits from avoided impoundment failures	No impact. BCA estimates are unchanged.	6
Air-related benefits	No impact. BCA estimates are unchanged.	7
Benefits from reduced water withdrawals	No impact. BCA estimates are unchanged.	8
Benefits from avoided dredging costs	Revisions may reduce benefits, relative to estimates presented in Chapter 9.	9
Benefits from enhanced marketability of coal combustion residuals	No impact. BCA estimates are unchanged.	10

Source: U.S. EPA Analysis, 2015

1.5 Analytic Framework

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

1. All values are presented in 2013 dollars;
2. Future benefits and costs are discounted using rates of 3 percent and 7 percent back to 2015;
3. Benefits and costs are analyzed over a 24-year period (2019 to 2042); and
4. Future values account for annual U.S. population and income growth.

These components are discussed in the sections below.

EPA's analysis of the final ELGs generally follows the methodology the Agency used previously to analyze the proposed ELGs (see *Benefit and Cost Analysis for the Proposed Effluent Limitations Guidelines and Standards for the Steam Electric Power Generating Point Source Category* (U.S. EPA, 2013a; DCN SE03172). In analyzing the final ELGs, however, EPA made several important changes relative to the analysis of the proposed rule:

- ➢ EPA used revised inputs that reflect the costs and loads estimated for the final regulatory options (see *TDD* and *RIA* for details).
- ➢ EPA updated the universe and characteristics of steam electric power plants to reflect generating units that have been announced to retire or convert (e.g., to natural gas) during the period of analysis as well as the anticipated effects of other regulations affecting the power sector and which may change operations and wastestreams of steam electric power plants.
- ➢ EPA updated the baseline scenario to reflect the projected effects of the CCR rule, including regarding the residual environmental risks from CCR impoundments.
- ➢ EPA revised assumptions to use more recent data (*e.g.*, analysis year, compliance period, dollar year adjustments).
- ➢ Finally, EPA made certain changes to the methodologies to address comments EPA received on the proposed rule (*e.g.*, Environmental Justice analysis), to be consistent with approaches used by the Agency for other rules, and to incorporate recent advances in the health risk and resource valuation research.

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

The benefits and social cost analyses presented in this document are generally based on loading reductions and other inputs generated for individual steam electric power plants (for all plants that were surveyed). These inputs are used to determine surface waters and other resources affected by steam electric power plant discharges, estimate changes in pollutant levels, identify populations exposed to steam electric pollutants, etc.

1.5.1 Constant Prices

This BCA applies a year 2013 constant price level to all future annual monetary values of costs and benefits. Some monetary values of benefits and costs are based on actual past market price data (*i.e.*, prior to 2013), and in those instances, EPA updated the prices to 2013 by multiplying them by appropriate indexes, or specific sub-components of these general indexes (index-updated prices). However, not all dollar-monetized

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

benefits and costs in this BCA are based on actual market prices of goods or services. Several categories of benefits presented in this report are estimated based on household willingness-to-pay (WTP) surveys, such as WTP for surface water quality improvements for monetizing ecological benefits of the final ELGs. This BCA updates these non-market prices as needed using appropriate indexes (*e.g.*, Consumer Price Index (CPI)).

1.5.2 Discount Rate and Year

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

All future cost and benefit values are discounted back to 2015.

1.5.3 Period of Analysis

Benefits are expected to begin accruing when each plant implements the control technologies needed to comply with any applicable new effluent limits or standards. As discussed in the *RIA* (in *Chapter 3: Compliance Costs*), for the purpose of the economic impact and benefit analysis, EPA assumes that plants will implement control technologies to meet the final rule limitations and standards as their permits are renewed over the period of 2019 through 2023. This schedule recognizes that control technology implementation is likely to be staggered over time across the universe of steam electric power plants.

As discussed in the relevant sections of this document, for several benefit categories where environmental changes are not provided on a plant-specific basis (*e.g.*, reduced air emissions or changes in surface water quality attributed to multiple plants), EPA was not able to use plant-specific assumed compliance years in the benefits analysis but instead used the mid-point of the compliance period (2021) as the assumed starting year when benefits begin accruing. As presented in the RIA (Table 3-1; U.S. EPA 2015c), over half of the plants potentially incurring costs for the final ELGs (under Option E) have their technology implementation year in 2021 or earlier.

The period of analysis extends to 2042 to capture the life of the longest-lived compliance technology at any steam electric power plant (20 years), and the last year of technology implementation (2023).

1.5.4 Population and Income Growth

To account for future population growth or decline, EPA used the population forecasts in Woods & Poole (2012), which developed county-level forecasts for each year from 2000 through 2040, by age and gender for non-Hispanic White, African-American, Asian-American, and Native-American and for all Hispanics.[5] EPA aggregated the population forecasts across all ages, genders, races, and ethnicities for the entire U.S. and used the aggregated growth projections to adjust affected population estimates for future years (*i.e.*, from 2019 to 2040). EPA used a linear extrapolation approach to forecast population values between 2040 and 2042.

Also, since WTP is expected to increase as income increases, EPA took into account income growth for estimating the value of avoided premature mortality based on the value of a statistical life (VSL) and WTP for

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[5] Woods and Poole (2012); the detailed documentation can be found at http://www.woodsandpoole.com/pdfs/CED12.pdf.

water quality (WQ) improvements. To develop adjustment factors for VSL, EPA first used income growth factors in the Environmental Benefits Mapping and Analysis Program (BenMAP) database between 1990 and 2024 to estimate a linear regression model. Using coefficient estimates from the linear regression, EPA extrapolated the income growth factors for years 2025-2042. EPA applied the projected income data along with the income elasticity for the respective models (VSL and meta-regression) to adjust the VSL and WQ meta-analysis estimates of WTP in future years.[6]

1.6 Organization of the Benefit and Cost Analysis Report

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

The remainder of this report is organized as follows:

- *Chapter 2: Benefits Overview* provides an overview of the main benefits expected to result from the implementation of the ELGs.
- *Chapter 3: Human Health Benefits* details the methods and results of EPA's analysis of the human health benefits.
- *Chapter 4: Nonmarket Benefits from Water Quality Improvements* discusses EPA's analysis of the surface water quality improvements resulting from the ELGs.
- *Chapter 5: Impacts and Benefits to Threatened and Endangered Species* discusses expected benefits to threatened and endangered (T&E) species.
- *Chapter 6: Benefits from Avoided Impoundment Failures* assesses the benefits of reducing the impacts of any future CCR releases from impoundments used by some steam electric power plants to manage their CCR waste.
- *Chapter 7: Air-Related Benefits* describes EPA's analysis of benefits associated with changes in emissions of air pollutants due to increased electricity consumption, transportation, and changes in the profile of electricity generation.
- *Chapter 8: Benefits from Reduced Water Withdrawals* discusses benefits arising from reduced surface water intake and groundwater use.
- *Chapter 9: Benefits from Avoided Dredging Costs* describes benefits from reduced maintenance dredging of navigational channels and reservoirs.
- *Chapter 10: Benefits from Enhanced Marketability of Coal Combustion Residuals* discusses benefits arising from the enhanced ability by plants to market dry coal combustion ashes.
- *Chapter 11: Summary of Total Monetized Benefits* summarizes results across benefit categories.
- *Chapter 12: Summary of Total Costs* summarizes costs of the ELGs.
- *Chapter 13: Benefits and* addresses the requirements of Executive Orders that EPA is required to satisfy for this proposal, notably Executive Order 12866, which requires EPA to compare the benefits and costs of its actions.

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[6] These extrapolated income growth factors were originally developed for EPA's COBRA tool (http://epa.gov/statelocalclimate/resources/cobra.html). The latest public version is 2.613 released in September 2014.

- *Chapter 14: Environmental Justice* details EPA's analysis of the distribution of benefits across socioeconomic groups to fulfill requirements under Executive Order (E.O.) 12898.
- *Chapter 15* provides references cited in the text.

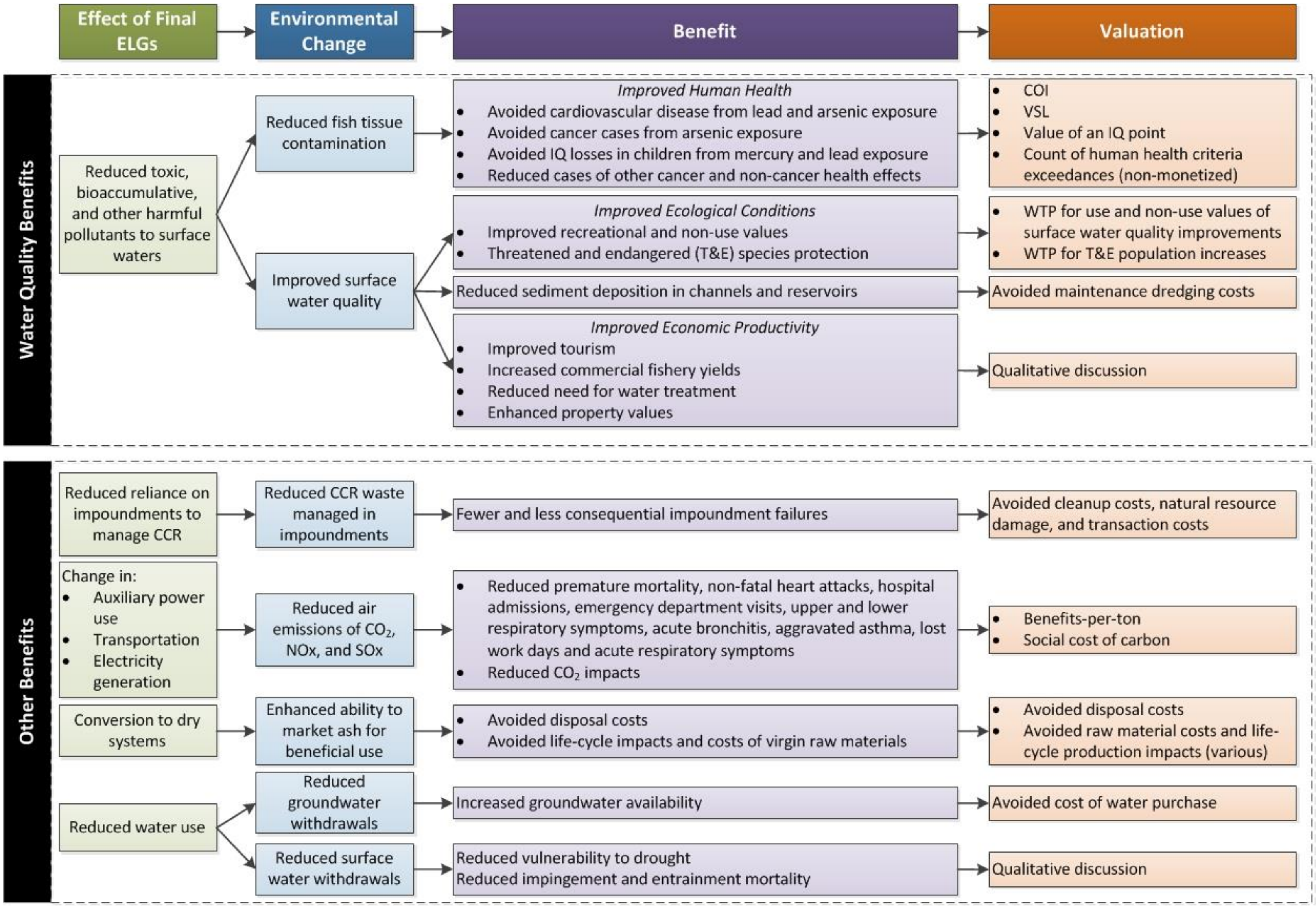
Several appendices provide additional details on selected aspects of analyses described in the main text of the report. In particular, *Appendix B* presents the results of EPA's analysis of the benefits for an alternate scenario using a baseline that excludes the incremental conversions, retirements, and other changes projected to occur in response to the CPP rule.

2 Benefits Overview

This chapter provides an overview of the potential benefits to society resulting from implementation of the ELGs. EPA expects that benefits will accrue to society in several broad categories, including enhanced surface water quality, reduced health risks, and increased productivity in economic activities that are adversely affected by steam electric discharges. These effects follow directly from changes in effluent limits and standards, which will reduce pollutant loadings to receiving waters. Benefits of the ELGs also include other effects of the implementation of control technologies or other changes in plant operations, such as reduction in emissions of air pollutants (*e.g.*, carbon dioxide (CO_2), nitrogen oxides (NO_X), and sulfur dioxide (SO_2)) which provide benefits in the form of reduced mortality and CO_2 impacts on environmental quality and economic activities; reduction in water use, which provide benefits in the form of increased availability of surface water and groundwater; and reduction in the use of surface impoundment to manage CCR wastes, with benefits in the form of avoided cleanup and other costs associated with impoundment releases.

This chapter also provides a brief discussion of the steam electric pollutants, their human health and ecological effects, and a framework for understanding the benefits expected to be achieved by the steam electric ELGs. For a more detailed description of steam electric pollutants, their fate, transport, and impacts on human health and environment, see the Environmental Assessment document (U.S. EPA, 2015a).

Figure 2-1 summarizes the potential effects of the ELGs, the expected environmental changes, and categories of benefits, as well as EPA's approach to analyzing those benefits. EPA was not able to bring the same depth of analysis to all categories of benefits because of imperfect understanding of the link between discharge reductions or other environmental effects of the ELGs and benefit categories, and how society values some of the benefits. EPA was able to quantify and monetize some benefits, quantify but not monetize other benefits, and assess still other benefits only qualitatively. The remainder of this chapter provides a qualitative discussion of the benefit categories applicable to this rule, including human health benefits, ecological benefits, improved groundwater quality, economic productivity, and reduced air pollution and water withdrawals. Some benefits estimates presented in this document rely on complex models that embed a variety of assumptions, limitations and uncertainties discussed in more details in chapters 3 through 10 for the relevant benefit categories.



COI = Cost of illness; VSL = Value of Statistical Life; WTP = Willingness to Pay; CCR = Coal Combustion Residuals

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

2.1 Human Health Benefits Associated with Improvements in Surface Water Quality

Pollutants present in steam electric plant discharges can cause a wide variety of adverse human health effects arising, for example, from consuming contaminated fish tissue. Toxic bioaccumulative pollutants are of particular concern because they do not volatilize, do not biodegrade, can be toxic to plants, invertebrates and fish, adsorb to sediments, and bio-concentrate in fish tissues (U.S. EPA, 2003). More details on the fate, transport, and exposure risks of steam electric pollutants are provided in the EA (U.S. EPA, 2015a).

Reducing pollutant discharges to the nation's waterways provides human health benefits by several mechanisms. The most important and readily analyzed benefits stem from reduced risk of illness associated with the consumption of water, fish, shellfish, and other aquatic organisms that are taken from waterways affected by steam electric discharges. Human health benefits are typically analyzed by estimating the change in the expected number of adverse human health events in the exposed population resulting from a reduction in effluent discharges. While some health effects (*e.g.*, cancer or mortality from cardiovascular disease (CVD)) 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 ELGs provide human health benefits by reducing exposure to pollutants in water via two principal exposure pathways discussed below: (1) consumption of fish and shellfish taken from waterways affected by steam electric discharges, and (2) consumption of water from surface waters affected by steam electric power plant discharges. The ELGs also provide human health benefits by reducing air emissions of pollutants via changes in the profile of electricity generation; these benefits are discussed separately in *Section 2.5*.

2.1.1 Fish Consumption

Recreational anglers and subsistence fishers (and their household members) who consume fish caught in the reaches receiving steam electric power plant discharges are expected to benefit from reduced pollutant concentrations in fish tissue. EPA analyzed the following five direct measures of change in risk to human health from exposure to contaminated fish tissue:

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

EPA was able to monetize only the first three of these four measures. The Agency evaluated lead and mercury impacts to children in terms of potential intellectual impairment as measured by estimated changes in intelligence quotient (IQ). Incidence of cardiovascular diseases was translated into an expected level of avoided early mortality and, on that basis, monetized. Incidence of cancer was translated into an expected number of avoided cases and monetized based on avoided costs. *Chapter 3* of this report provides details on these analyses.

The fifth effect (reduced risk of other cancer and non-cancer toxic effects from fish consumption) is addressed indirectly in EPA's assessment of changes in exceedances of ambient water quality criteria (see *Section 3.8*).

The value of health benefits is the monetary value that society is willing to pay to avoid the adverse health effects. WTP to avoid morbidity or mortality is generally considered to be a comprehensive measure of the costs of health care, losses in income, and pain and suffering of affected individuals and their caregivers. For example, the value of a statistical life (VSL) (see *Section 3.4*) is based on estimates of society's WTP to avoid the risk of premature mortality. Alternatively, the cost-of-illness (COI) approach, which is used to estimate the value of avoided skin cancer cases (see *Section 3.6*), is a less comprehensive measure of cost: it allows valuation of a particular type of non-fatal illness by placing monetary values on metrics, such as lost productivity and the cost of health care and medications that can be monetized.

Some health benefits of reduced 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 since available economic research provides little empirical data on society's WTP to avoid IQ losses. Instead, EPA calculated monetary values for avoided 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 benefits from reduced exposure to lead and mercury. Employed alone, these monetized benefits will underestimate society's WTP, and perhaps significantly so. See *Sections 3.3* and *3.5* for applications of this method to valuing benefits to children and infants from reduced exposure to lead and mercury.

EPA expects that there could also be material health benefits via the fish consumption pathway arising from reduced discharges of other steam electric pollutants, such as cadmium, selenium, and zinc. Analyses of these health benefits are not possible due to lack of data on a quantitative relationship between ingestion rate and potential adverse health effects.

Despite numerous studies conducted by EPA and other researchers, dose-response functions are available only for a handful of health endpoints associated with steam electric pollutants. In addition, the available research does not always allow complete economic evaluation, even for quantifiable health effects. For example, EPA's analysis of health benefits omits the following health effects: low birth weight and neonatal mortality from in-utero exposure to lead (U.S. EPA, 2009d); additional effects to adults from exposure to lead (*e.g.*, nervous system disorders, anemia and blood disorders) (U.S. EPA, 2009d; 2013a); effects to adults from exposure to mercury, including vision defects, hand-eye coordination, hearing loss, tremors, cerebellar changes, and others (Mergler, et al., 2007; CDC, 2009); and other cancer and non-cancer effects from exposure to other steam electric pollutants. Therefore, the total monetized human health benefits included in this analysis represent only a subset of the potential health benefits that are expected to result from the ELGs.

2.1.2 Drinking Water Consumption

Steam electric pollutants discharged to surface waters may affect the quality of water used for public drinking supplies. However, public drinking water supplies are subject to legally enforceable maximum contaminant levels (MCLs) established by EPA (U.S. EPA, 2012a). 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.

Pursuant to MCLs, public drinking water supplies are already treated for pollutants that pose human health risks. 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, 2013d). There may therefore be some incremental health-related benefits associated with reduced concentrations arising from the final ELGs. However, EPA's screening level analysis suggests that these benefits would not be substantial. As a first step in assessing the potential benefits, EPA determined that 27 directly receiving reaches have metal concentrations above the MCL in the baseline. None of those reaches, however, has an associated drinking water intake. Based on the analysis of the larger set of reaches (including downstream reaches) there are 817 reaches with MCL exceedances in the baseline; 250 of these reaches improve under the final ELGs. However, again, none of these improving reaches has an associated drinking water intake. Accordingly, EPA restricted the analysis of monetized health benefits from improved surface water quality to benefits arising from the consumption of contaminated fish tissue.

2.1.3 Complementary Measure of Human Health Benefits

EPA quantified but did not monetize the expected reduction of pollutant concentrations in excess of human health-based ambient water quality criteria (AWQC) limits. This analysis provides a measure of the change in cancer and non-cancer health risk by comparing the number of receiving reaches exceeding health-based AWQC for steam electric pollutants in the baseline to the number exceeding AWQC under the regulatory options (*Section 3.8*).

Because AWQC are set at levels to protect human health through ingestion of water and aquatic organisms, reducing the frequency at which human health-based AWQC are exceeded should translate into reduced risk to human health. This measure should be viewed as an indirect indicator of reduced risk to human health because it does not reflect the size of the exposed population and does not quantify changes in human health risk per se.

2.2 Ecological Benefits Associated with Improvements in Surface Water Quality

The composition of steam electric power plant wastewater depends on a variety of factors, such as fuel composition, air pollution control technologies used, and waste management techniques used; wastewater often contains metals such as aluminum, arsenic, boron, cadmium, chromium, copper, iron, lead, manganese, mercury, nickel, selenium, thallium, vanadium, and zinc (U.S. EPA, 2015a). Discharges of these pollutants to surface water has 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, 2015a). 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.

EPA expects the ecological benefits from the ELGs to include enhanced habitat 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 reduction in pollutant loadings is expected to reestablish productive ecosystems in damaged waterways and to protect resident species, including threatened and endangered species. EPA expects the regulation to enhance the general health of fish and invertebrate populations, increase their propagation to waters currently impaired, and expand fisheries for both commercial and recreational purposes. Improvements in water quality will also favor recreational activities such as swimming, boating, fishing, and water skiing. Finally, the Agency expects the regulation to augment nonuse values (*e.g.*, option, existence, and bequest values) of the affected water resources.

2.2.1 Improved Surface Water Quality

The steam electric ELGs are expected to provide ecological benefits through improvements in the habitats or ecosystems (aquatic and terrestrial) that are affected by steam electric power plant discharges. Society values such ecological improvements by a number of mechanisms, including increased frequency and value of use of the improved habitat for recreational activities. In addition, individuals also value the protection of habitats and species that are adversely affected by effluent discharges, even when those individuals do not use or anticipate future use of the affected waterways for recreational or other purposes, resulting in nonuse values.

Recreational activities that may be enhanced by reducing steam electric discharges to surface waters include:

- *Recreational Fishing.* Degraded water can reduce fish populations by inhibiting reproduction, growth, and survival of an aquatic species (Friedman et al. 1996; Niimi and Kissoon 1994; U.S. EPA, 2009d; U.S. EPA, 2011a) resulting in fewer and smaller fish and thereby reducing the value of a fishing trip. Reducing pollutant loads in steam electric power plant discharges is expected to improve aquatic habitat and thus increase the number, size, diversity, and health of recreational fish species and, as a result, the value of recreational fishing. Studies have shown that the value of water resources for recreational fishing increases with declining level of toxic contamination in fish tissue (Phaneuf et al., 1998; and Jakus et al., 1997). In addition, improved aesthetic qualities of the waterbody (*e.g.*, from reduced nutrient loadings) and knowledge that the water is cleaner and does not contain any or contains fewer pollutants that harm humans and aquatic life, increases individuals' enjoyment of their recreational experience.
- *Outings.* Participants in other recreational activities such as hiking, jogging, picnicking, and wildlife viewing also benefit from improved abundance and diversity of aquatic and terrestrial species. For example, wildlife viewers benefit from improved abundance of piscivorous birds (*e.g.*, osprey, eagle) and waterfowl whose populations are likely to increase due to a reduction of mercury and other heavy metals in the food web and an increase in the forage fish populations (Schoch et al., 2011; U.S. EPA, 2011a). In addition, improved aesthetic quality of surface waters (*e.g.*, clarity and odors) enhances the recreational experience of wildlife viewers and other recreational users. (Schoch et al., 2011; U.S. EPA, 2011a).
- *Boating.* Boaters benefit from enhanced opportunities for companion activities, such as fishing and wildlife viewing (*e.g.*, piscivorous birds), and from improved aesthetic quality.
- *Swimming.* Swimmers benefit from improved aesthetic quality of surface waters including water clarity and odor thereby enhancing swimmer's aesthetic enjoyment of a waterbody.
- *Hunting.* Waterfowl hunters benefit from improved aesthetic enjoyment of a water resource, an increase in the number and quality of game available, and the removal of waterfowl consumption advisories. Reducing nutrient loadings from steam electric power plants is likely to benefit diving ducks populations by reducing eutrophication and turbidity in the affected waters and improving their food sources. Diving ducks rely upon undisturbed and abundant plant and invertebrate sources to prepare for migration. Excessive nutrient loadings can lead to eutrophic and turbid waters, with few plants and invertebrates food sources (Minnesota Department of Natural Resources (MDNR), 2010). Waterfowl populations are adversely affected by consuming contaminated fish or invertebrates; zebra mussels are an attractive food source for ducks and have been found to have high concentrations of methyl mercury (MDNR, 2010). High mercury levels have led to duck consumption advisories (Utah Department of Natural Resources, 2005). Reduction in metal loading to surface waters and of their presence in the food web may benefit waterfowl reproduction and lead to removal of duck consumption advisories.

EPA quantified potential ecological impacts from the final ELG options by estimating in-waterway concentrations of nutrients and other harmful pollutants discharged by steam electric power plants and translating water quality measurements into a single numerical indicator (water quality index (WQI)). EPA used the estimated change in WQI as a quantitative measure of ecological benefit for this regulatory analysis.

Section 4.1 of this report provides detail on the parameters used in formulating the WQI and the WQI methodology and calculations.

A variety of primary methods exist for estimating recreational use values, including both revealed and stated preference methods (Freeman, 2003). Where appropriate data are available or can be collected, revealed preference methods can represent a preferred set of methods for estimating use values. These 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; U.S. OMB, 2003). Stated preference methods rely on carefully designed surveys, which either (1) ask people about their WTP for particular ecological improvements, such as increased protection of aquatic species or habitats with particular attributes, or (2) ask people to choose between competing hypothetical "packages" of ecological improvements and household cost (Bateman et al., 2006). In either case, values are estimated by statistical analysis of survey responses.

Although the use of primary research to estimate values is generally preferred because it affords the opportunity for the valuation questions to closely match the policy scenario, the realities of the regulatory process often dictate that benefit transfer is the only option for assessing certain types of non-market values (Rosenberger and Johnston, 2007). Thus, EPA developed a benefit transfer approach based on a meta-analysis of surface water valuation studies to evaluate the use and non-use benefits of improved surface water quality resulting from the final rule. This analysis is presented in *Chapter 4*. 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 and De Civita, 1999). In the benefit transfer used for analyzing non-market benefits associated with water quality improvements, EPA used a regression-based meta-analysis of 140 estimates of total WTP (including both use and nonuse values) for water quality improvements, provided by 51 original studies conducted between 1981 and 2011.[7] The estimated econometric model allows calculation of total WTP for improvements in a variety of environmental services affected by water quality and valued by humans, including enhanced recreational fishing, 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: 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.

2.2.2 Benefits to Threatened and Endangered Species

For threatened and endangered (T&E) species vulnerable to future extinction, even minor changes to reproductive rates and small levels of mortality may represent a substantial portion of annual population growth. Consequently, steam electric power plant discharges may either lengthen recovery time, or hasten the demise of these species. By reducing the discharge of steam electric pollutants to aquatic habitats, the ELGs are expected to enhance 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

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[7] Although the potential limitations and challenges of benefit transfer are well established (Desvousges et al., 1998), 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."

use activities general constitute take, which is illegal unless permitted, the majority of the economic value for T&E species comes from nonuse values.

Species-specific estimates of nonuse values held for the protection of T&E species can be derived only by primary research using stated preference techniques. As a second-best alternative,[8] EPA used a benefit transfer approach that relies on information from existing studies (U.S. EPA, 2010a). This benefit transfer approach is based on a meta-analysis of 31 stated preference studies valuing threatened, rare, or endangered fish, bird or mammal species (Richardson and Loomis, 2009). EPA used the estimated WTP equation provided in this meta-analysis to estimate the monetary value of the potential increases in T&E populations resulting from the ELGs. This analysis and results are presented in *Chapter 5*. WTP values for improvements in water quality discussed in the preceding section may inherently include benefits to T&E species. Although there may be some overlap between WTP estimates for T&E species and the WTP estimates for improvements in water quality, this overlap is likely to be minimal, however, since none of the studies in EPA's meta-analysis of WTP for water quality improvements specifically mentioned or otherwise prompted respondents to include benefits to T&E species populations (see *Chapter 4*).

2.2.3 Reduced Sediment Contamination

Effluent discharges from steam electric power plants can also contaminate waterbody sediments. For example, adsorption of arsenic, selenium, and other pollutants found in steam electric power plant discharges can result in accumulation of contaminated sediment on stream and lake beds (Ruhl, et al., 2012), posing a particular threat to benthic (*i.e.*, bottom-dwelling) organisms. These pollutants can later be re-released into the water column and enter organisms at different trophic levels; concentrations of selenium and other steam electric 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).

By reducing discharges of pollutants to receiving reaches, the ELGs are expected to reduce the future contamination of waterbody sediments, thereby mitigating impacts to benthic organisms and reducing the probability that the pollutants would 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 this benefit.

2.3 Benefits Associated with Improvements in Groundwater Quality

Impoundments used by steam electric power plants to manage their wastewater can leach pollutants into groundwater aquifers, degrading water quality and potentially creating health hazards to households drawing drinking water from affected aquifers. The operational changes prompted by the ELGs are expected to result in plants ceasing or significantly reducing their use of impoundments to manage coal combustion residuals (CCR). EPA estimated benefits from reducing the risk of groundwater contamination as part of its analysis of the proposed ELG options (U.S. EPA, 2013a). In December 2014, EPA promulgated the CCR rule which specifically addresses risks to groundwater quality from leaking impoundments. The CCR rule establishes technical requirements for CCR surface impoundments, including composite liners, groundwater monitoring, corrective action, and closure/post closure care, among others. For example, the rule requires any existing unlined CCR surface impoundment that is contaminating groundwater above a regulated constituent's groundwater protection standard to stop receiving CCR and either retrofit or close, and that corrective action be taken to address contamination from leaking clay- or composite-lined impoundments. The final ELGs may still provide groundwater protection benefits, however, by reducing the potential impacts of future

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[8] The cost, administrative burden, and time required to develop primary research estimates to value effects of the regulation on T&E species were beyond the schedule and resources available for this rulemaking.

impoundment leaks, thereby avoiding future corrective action costs. EPA does not have sufficient data to model the avoidance of future leaks of clay- or composite-lined impoundments that may no longer receive CCR as a result of the final ELGs. EPA's analysis of the CCR rule showed significantly lower lifetime risk of groundwater contamination from lined impoundments than from unlined impoundments (4 and 300 times smaller risk for clay- and composite-lined impoundments respectively), which suggests that corrective actions associated with lined impoundments should be infrequent. Accordingly, EPA estimates that the residual risk to aquifers after implementation of the CCR rule is small and did not estimate incremental benefits for the ELGs.

2.4 Economic Productivity Benefits

The economic productivity benefits expected to result from the ELGs include reduced impacts of impoundment releases of CCR and the reduction in the costs associated with the resulting cleanup, environmental damages, and transaction costs. Conversion to dry handling systems to comply with the ELG are expected to provide economic benefits by enhancing the ability of steam electric power plants to market the ash for beneficial use (*e.g.*, in concrete or fill), thereby reducing the disposal costs otherwise incurred by steam electric power plants and displacing resource intensive virgin materials. Other economic productivity benefits may stem from reduced contamination of public drinking water supplies and irrigation water; increased tourism; increased commercial fish harvests; and increased property values.

2.4.1 Reduced Impoundment Releases

Steam electric power plants manage CCR such as fly ash and bottom ash through either wet or dry handling. For plants that use wet handling, the waste is typically sluiced to one or more surface impoundments (*e.g.*, settling ponds), where the solids settle out of the water. Many plants also use surface impoundments to manage their flue gas desulfurization (FGD) wastewater. In addition to solids associated with the ash and FGD wastes, these impoundments typically contain water with high concentrations of steam electric pollutants, including dissolved metals.

The operational changes prompted by the ELGs, such as conversion to dry handling, are expected to cause some plant owners to reduce their reliance on impoundments to handle CCR. These changes could affect the volume of CCR released in the event of a failure and/or the future probability of impoundment releases. Benefits arising from the reduced risk of impoundment releases include avoided cleanup costs, environmental damage, and transaction costs.

EPA quantified and monetized these benefits based on expected future impoundment release rates, the volumes of CCR that would be released in an incident, and the costs of cleanup, natural resource damages, and transaction costs. *Chapter 6* describes this analysis.

2.4.2 Enhanced Marketability of Coal Ash for Beneficial Use

EPA anticipates that the final ELGs will prompt certain plants to convert from wet handling of fly ash, bottom ash, and/or FGD waste to dry handling. This change would in turn allow plants to more readily market the CCR to beneficial uses. EPA quantified and monetized changes in the marketability of two CCR wastestreams, and two end uses: (1) fly ash as a substitute for Portland cement in concrete production and (2) fly- and bottom ashes as substitutes for sand and gravel in fill applications. The changes are based on the tonnage of fly and bottom ash handled dry instead of wet, with benefits derived from plants avoiding certain costs associated with disposing of the ashes as waste and society or users of the ash avoiding the cost and life-cycle effects associated with the displaced virgin material. *Chapter 10* describes this analysis.

2.4.3 Water Supply and Use

The ELGs are expected to reduce loading of steam electric pollutants to surface waters and thus enhance uses of these waters for drinking water supply and agriculture:

- *Drinking water treatment costs*. The ELGs have the potential to reduce costs of drinking water treatment (*e.g.*, filtration and chemical treatment) by reducing metal concentrations and eutrophication in source waters. Eutrophication is one of the main causes of taste and odor impairment in drinking water, which has a major negative impact on public perceptions of drinking water safety. Additional treatment to address foul tastes and odors can significantly increase the cost of public water supply. The Agency conducted screening-level assessment to evaluate the potential for cost saving to public drinking water systems and concluded that such savings, while they exist, may not be significant. The assessment involved identifying the pollutants for which treatment costs may vary depending on source water quality, and using data from EPA's ELG analysis and the location of drinking water intakes to determine whether modeled water quality improvements have the potential to reduce drinking water treatment costs. During the first step in the assessment, EPA determined that water utilities may see reduced costs for the removal of arsenic, cadmium, copper, lead, mercury, selenium, thallium, nitrogen, and total suspended solids. During the second step in the assessment, EPA determined that few drinking water systems are currently drawing water at levels that exceed one or more MCLs and would improve under the policy options. And similarly, few reaches with elevated total nitrogen (TN) levels will see those levels decline significantly under the regulatory options to result in substantive cost savings. Accordingly, EPA did not conduct detailed analysis of cost savings to publicly operated treatment systems.
- *Reduction in bromide concentrations*. Public drinking water sources do not always effectively remove bromides (a steam electric pollutant) from raw surface waters. While bromide itself is not thought to be toxic at levels present in the environment, lab studies and case reports show that bromide found in source water can react during routine drinking water treatment to generate harmful disinfection byproducts (DBPs) (Richardson, et al., 2007; U.S. EPA, 2012a). For example, McTigue et al. (2014) estimate that 96 drinking water treatment plants using surface water are downstream of 57 coal-fired power plants using wet scrubbers. If existing water treatment is not sufficient, an alternate water source needs to be substituted or developed, or alternate disinfection technologies need to be adopted (Watson, et al., 2012). Long-term solutions might require the development of new raw water supplies, which would involve costs for the acquisition of land (if available), regulatory review and permitting, development of infrastructure (dams, pumps, pipes), and watershed protection. Thus, increased bromide levels in raw source water could translate into additional drinking water treatment costs at some plants, and potentially pose human health risk. In this Final Rule, EPA is not proposing technology-based effluent limits for bromide for steam electric industry. However, NPDES permit developers could specify effluent limits for bromide on a plant-by-plant basis based on site-specific considerations that include the potential to affect public drinking water sources. Benefits of any plant-specific limits in terms of avoided treatment costs or human health risk would need to be determined based on more detailed information about the receiving waters and drinking water system.
- *Irrigation and other agricultural uses*: Reducing steam electric pollutants discharges can improve agricultural productivity by improving water quality used for irrigation and livestock watering (Clark et al., 1985). Although elevated nutrient concentrations in irrigation water would not adversely affect its usefulness for plants, concerns exist for potential residual effects due to steam electric pollutants entering the food chain. Further, eutrophication promotes cyanobacteria blooms that can kill livestock

and wildlife that drink the contaminated surface water. EPA did not quantify or monetize benefits from enhanced quality agricultural water sources arising from the ELGs due to data limitations.

- *Reservoir Capacity*. Reservoirs serve many functions, including storage of drinking and irrigation water supplies, flood control, hydropower supply, and recreation. Streams can carry sediment into reservoirs, where it can settle and cause buildup of silt layers over time, at a recorded average rate of 1.2 billion kilograms per reservoir every year (USGS, 2007b). 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). EPA expects that by reducing total suspended solids (TSS) concentrations, the ELGs will provide modest cost savings by reducing dredging activity to reclaim capacity at existing reservoirs.

2.4.4 Reduced Sedimentation in Navigational Waterways

Navigable waterways, including rivers, lakes, bays, shipping channels and harbors, are an integral part of the United States' transportation network. 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). For many navigable waters, periodic dredging is necessary to remove sediment and keep them passable. Dredging of navigable waterways can be costly.

EPA expects that the ELGs will reduce sediment loadings to surface waters and reduce dredging of navigational waterways and reservoirs. EPA quantified and monetized these benefits based on the avoided cost for expected future dredging volumes. *Chapter 9* describes this analysis.

2.4.5 Commercial Fisheries

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

EPA did not quantify or monetize benefits to commercial fisheries from the ELGs. EPA's EA (see U.S. EPA, 2015a) shows that a small number of steam electric power plants discharge to estuaries or marine waters. Although benefits to local fish populations and commercial harvest may be positive, the overall benefits to commercial fisheries arising from the ELGs are likely to be negligible. Most species of fish have numerous close substitutes. The literature suggests that when there are plentiful substitute fish products, numerous fishers, and a strong ex-vessel market, individual fishers are generally price takers. Therefore, the measure of consumers welfare (consumer surplus) is unlikely to change as a result of small changes in fish landings, such as those EPA expects under the final rule.

2.4.6 Tourism

The ELGs may also benefit local economies by contributing to the tourism industries (*e.g.*, sales of fishing equipment) in the areas surrounding affected waters due to improved recreational opportunities. The effects of water quality on tourism are likely to be highly localized. Moreover, since substitute tourism locations may be available, increased tourism in the vicinity of steam electric power plants may lead to a reduction in tourism in other locations. Due to these factors EPA believes that benefit from an increase in tourism would be limited to communities in the vicinity of steam electric power plants; although tourism revenue is potentially important to these communities, the overall societal benefits are likely to be small. Therefore, EPA did not quantify or monetize this benefit category.

2.4.7 Property Values

The ELGs are expected to improve the aesthetic quality of land and water resources by reducing pollutant discharges and thus enhancing water clarity, odor, and color in the receiving and downstream reaches. Several studies (Boyle et al., 1999; Poor et al., 2001; Leggett and Bockstael, 2000; Bin and Czakowski, 2013; Walsh et al., 2011; Tuttle and Heintzelman, 2014) suggest that waterfront property is more desirable when located near unpolluted water. Therefore, the value of properties located in proximity to waters contaminated with steam electric pollutants may increase due to reduced steam electric discharges. Although this benefit would accrue to the current property owners only, it represents an overall increase in societal wealth.

Due to data limitations, EPA was not able to quantify or monetize the potential increase in property values associated with the ELGs. The magnitude of the potential increase depends on many factors, including the number of housing units located in the vicinity of the affected waterbodies, community (*e.g.*, residential density) and housing stock (*e.g.*, single family or multiple family) and the effects of steam electric pollutants on aesthetic quality of surface water. Given that the main benefit of the final ELG is reduction in metal concentrations that do not affect aesthetic quality of surface water, changes in property values are expected to be small. In addition, there may be overlap between changes in property values and the estimated total WTP for surface water quality improvements summarized in *Section 2.2.1*.

2.5 Reduced Air Pollution

The ELGs are expected to affect air pollution through three main mechanisms: 1) additional auxiliary electricity use by steam electric power plants to operate wastewater treatment, ash handling, and other systems needed to comply with the new effluent limits and standards; 2) additional transportation-related emissions due to the increased trucking of CCR 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 for the ELGs. The different profile of generation can result in lower or higher air pollutant emissions due to differences in emission factors for coal or natural gas combustion, or nuclear or hydroelectric power generation.

Of the three mechanisms above, the change in the emissions profile of electricity generation at the market level is the most significant. Small reductions in coal-based electricity generation as a result of the final ELGs are compensated by increases in generation using other fuels or energy sources – biomass, landfill gas, natural gas, nuclear power, oil, and wind power. The changes in air emissions reflect the differences in emissions factors for these other fuels, as compared to coal-fueled generation. Overall for the three mechanisms (auxiliary services, transportation, and market-level generation), EPA estimates a net reduction in CO_2 and SO_2, and a slight increase in NO_X emissions.

NO_X, and SO_2 are known precursors to PM2.5, 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). To estimate benefits of reducing NO_X, and SO_2 emissions, EPA used estimates of national monetized benefits per ton of emissions avoided. CO_2 is an important greenhouse gas that is linked to climate change effects including global warming, sea level rise, increased frequency of extreme weather events, ocean acidification, etc. EPA used estimates of the social cost of carbon (SCC) obtained from the Interagency Working Group on Social Cost of Carbon (see Interagency Working Group on Social Cost of Carbon (IWGSCC), 2013b) to derive benefits per ton for CO_2. The SCC reflects a broad range of climate change impacts, including changes in agricultural productivity, human health risks, property damage from increased flood frequencies, the loss of ecosystem services, and others. *Chapter 7* details this analysis.

2.6 Reduced Water Withdrawals

Steam electric power plants use water for wet ash transport and for operating wet FGD scrubbers. By eliminating or reducing water used in sluicing operations or prompting the recycling of water in FGD wastewater treatment systems, the ELGs are expected to reduce demand on aquifers by plants that rely on groundwater sources.

Additionally, reduced surface water intake would reduce impingement and entrainment mortality. Due to data limitations, EPA did not quantify and monetize these benefits as part of this analysis. For more details on the impacts of surface water withdrawals, see paper titled “Water Withdrawals in Water Stressed Areas: Impacts of the Steam Electric Effluent Limitations Guidelines” (DCN SE05943) in the record for the final steam electric ELG rule.

Reduced water use from groundwater sources by steam electric power plants would result in greater availability of groundwater supplies for alternative uses. EPA used the state specific prices for bulk drinking water supplies to value the increased quantity of groundwater. This analysis is presented in *Chapter 8*.

2.7 Summary of Benefits Categories

Table 2-1 summarizes the benefits of the ELGs and the level of analysis applied to each category. As indicated in the table, only a subset of anticipated benefits can be quantified and monetized (in which case the table identifies the section of the report that discusses the analysis). The monetized benefits include reductions in some human health risks, use and non-use values from improved surface water quality, benefits to T&E species, reduced impacts from impoundment releases, increase in the amount of ash marketed for beneficial uses, reduced costs for dredging navigational waterways, reduced air pollution, and reduced water withdrawals. Other benefit categories, including expected reduction of pollutant concentrations in excess of human health-based AWQC limits, can be quantified but not monetized. Finally, EPA was not able to quantify or monetize other benefits, including drinking water treatment costs and benefits to commercial fisheries; EPA evaluated these benefits qualitatively as discussed above in *Sections 2.1* through *2.6*.

Table 2-1: Estimated Benefits of Reduced Pollutant Discharges from Steam Electric Power Plants

Category	Effect of ELGs	Benefits Analysis		
		Quantified	Monetized	Methods (Report Chapter or Section where Analysis is Detailed)
Human Health Benefits from Surface Water Quality Improvements				
Reduced IQ losses to children ages 0 to 7	Reduced childhood exposure to lead from fish consumption	✓	✓	IQ point valuation (*Section 3.3*)
Reduced need for specialized education	Reduced childhood exposure to lead from fish consumption	✓	✓	Avoided cost (*Section 3.3*)
Reduced incidence of cardiovascular disease	Reduced exposure to lead from fish consumption	✓	✓	VSL (*Section 3.4*)

Table 2-1: Estimated Benefits of Reduced Pollutant Discharges from Steam Electric Power Plants

Category	Effect of ELGs	Benefits Analysis		
		Quantified	**Monetized**	**Methods (Report Chapter or Section where Analysis is Detailed)**
Reduced IQ losses to infants	Reduced in-utero mercury exposure from maternal fish consumption	✓	✓	IQ point valuation (*Section 3.5*)
Reduced incidence of cancer	Reduced exposure to arsenic from fish consumption	✓	✓	COI (*Section 3.6*)
Reduced other adverse health effects (cancer and non-cancer)	Reduced exposure to other pollutants (arsenic, lead, etc.) via fish consumption	✓		Human health criteria exceedances (*Section 3.8*)
Reduced adverse health effects	Reduced exposure to pollutants from recreational water uses			Qualitative discussion
Ecological Conditions and Recreational use Benefits from Surface Water Quality Improvements				
Improved aquatic and wildlife habitat[a]	Improved ambient water quality in receiving reaches	✓	✓	Benefit transfer (*Chapter 4*)
Water-based recreation[a]	Enhanced swimming, fishing, boating, and near-water activities from improved water quality			
Aesthetics[a]	Increased aesthetics from improved water clarity, color, odor, including nearby site amenities (residing, working, traveling)			
Non-use values[a]	Enhanced existence, option, and bequest values from improved ecosystem health			
Aquatic and wildlife	Reduced risks to aquatic life from exposure to steam electric pollutants			
Improved protection of T&E species	Improved T&E habitat and thus potential increase in T&E population	✓	✓	Benefit transfer (*Chapter 5*)
Reduced sediment contamination	Reduced deposition of toxic pollutants to sediment			Qualitative discussion
Groundwater Quality Benefits				
Groundwater quality	Reduced groundwater contamination			Qualitative discussion
Market and Productivity Benefits				
Impoundment releases	Reduced risk of impoundment releases due to changes in the use of impoundment	✓	✓	Avoided cost of cleanup, natural resource damages, and transaction costs (*Chapter 6*)
Reduced dredging costs	Reduced costs for maintaining navigational waterways and reservoir capacity	✓	✓	Avoided dredging costs (*Chapter 9*)

Table 2-1: Estimated Benefits of Reduced Pollutant Discharges from Steam Electric Power Plants

Category	Effect of ELGs	Benefits Analysis		
		Quantified	**Monetized**	**Methods (Report Chapter or Section where Analysis is Detailed)**
Beneficial use of ash	Reduced disposal costs and avoided life-cycle impacts from displaced virgin material	✓	✓	Avoided disposal cost and avoided resource use and environmental impacts (*Chapter 10*)
Reduced water treatment costs for drinking water and irrigation water	Improved quality of source water used for drinking and irrigation			Qualitative discussion
Commercial fisheries	Improved fisheries yield and harvest quality due to aquatic habitat improvement			Qualitative discussion
Benefits to tourism industries	Increased participation in water-based recreation			Qualitative discussion
Property values	Increased property values from water quality improvements			Qualitative discussion
Air-Related Benefits				
Reduced air emissions of NO_x, SO_2	Reduced mortality and morbidity from exposure to NO_x, SO_2 and particulate matter ($PM_{2.5}$)	✓	✓	Benefit per ton of air pollutant removed (*Chapter 7*)
Reduced air emissions of CO_2	Avoided climate change /global warming impacts	✓	✓	Social cost of carbon (SCC) (*Chapter 7*)
Reduced Water Withdrawal Benefits				
Reduced groundwater withdrawals	Increased availability of groundwater resources	✓	✓	Avoided cost (*Chapter 8*)
Reduced surface water withdrawals	Reduced vulnerability to drought and reduced impingement and entrainment mortality			Qualitative discussion

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

3 Human Health Benefits

EPA expects that the ELGs will yield a range of human health benefits by reducing effluent discharges to surface waters and, as a result, ambient pollutant concentrations in the receiving reaches. EPA's EA (U.S. EPA, 2015a) provides details on the health effects of steam electric pollutants. Recreational anglers and subsistence fishers (and their household members) who consume fish caught in the reaches receiving steam electric discharges are expected to benefit from reduced pollutant concentrations in fish tissue. This chapter presents EPA's analysis of human health benefits from reduced exposure to steam electric pollutants via the fish consumption pathway.[9] The analyzed health benefits include:

- Reduced exposure to lead:
  - Avoided 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
  - Reduced incidence of CVD in adults
- Reduced exposure to mercury:
  - Reduced neurological and cognitive damages in infants from exposure to mercury *in-utero*
- Reduced exposure to arsenic:
  - Reduced incidence of cancer cases.

The total quantified human health benefits included in this analysis represent only a subset of the potential health benefits expected to result from the final ELGs. While additional adverse health effects are also associated with steam electric pollutants (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[10] between ingestion rates and these effects precluded EPA from quantifying the associated benefits.

EPA's analysis of the monetary value of human health benefits is based on data and methodologies described in the EA (U.S. EPA, 2015a). The relevant data include COMIDs[11] for receiving waters, baseline and post-compliance annual plant-level loadings of each discharged pollutant, ambient pollutant concentrations in receiving reaches and downstream reaches, pollutant concentrations in fish tissue, fish consumption rates among different racial and ethnic cohorts for affected recreational anglers and subsistence fishers, and the average daily dose (ADD) or lifetime average daily dose (LADD) of pollutants for each age cohort for recreational anglers and subsistence fishers.

Section 3.1 describes how EPA identified the population potentially exposed to pollutants from steam electric discharges via fish consumption. *Section 3.2* describes the methods for determining fish tissue pollutant concentrations and exposure via fish consumption in the affected population. *Sections 3.3* to *3.7* describe

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[9] The analysis of human health benefits focuses on the fish consumption pathway only, since EPA assumed that drinking water is treated to reduce pollutant concentrations below MCLs. See Chapter 2 for further discussion.

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

[11] A COMID is a unique numeric identifier for a given waterbody, assigned by a joint effort of the United States Geological Survey, EPA, and Horizon Systems, Inc.

EPA's analysis of benefits of various human health endpoints affected by the final ELGs. The human health benefits estimates rely on models of concentration-response and exposure pathways that embed assumptions and involve limitations and uncertainties. *Section 3.9* describes the limitations and uncertainties in the health benefit analyses.

3.1 **Affected Population**

The affected population (*i.e.*, individuals potentially exposed to steam electric pollutants via consumption of contaminated fish tissue) includes recreational anglers and subsistence fishers who fish reaches affected by steam electric discharges (including receiving and downstream reaches), as well as their household members. EPA estimated the number of people who are likely to fish affected reaches based on typical travel distances to a fishing site, presence of substitute fishing locations, data on the locations and status of fish consumption advisories (FCAs) for affected reaches, and information on anglers' awareness and adherence to FCAs. Since fish consumption rates vary across different racial and ethnic groups and across fishing mode (recreational versus subsistence fishing), EPA estimated benefits separately for a number of age-, ethnicity-, and mode-specific cohorts.

First, for each Census Block Group (CBG) within 50 miles of an affected reach, EPA pulled 2010 Census 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 or higher), and then subdivided each group according to 7 racial/ethnic categories:[12] 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[13]. Within each racial/ethnic group, EPA further subdivided the population according to recreational and subsistence groups, assuming that 5 percent of the population practices subsistence fishing.[14] Finally, 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.[15] After subdividing population groups by age, race, fishing mode, and the poverty indicator, each CBG has 196 unique population cohorts (7 age groups × 7 ethnic/racial groups × 2 exposure cohorts [recreational vs. 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 in baseline exposure to pollutants in steam electric power plant discharges, and to allow evaluation of the effects of the regulatory options on mitigating any EJ concerns. See *Chapter 14* for details of the EJ analysis. As noted below, distinguishing the exposed population in this manner also allows the Agency to account for differences in exposure among demographic groups, where supported by data.

Equation 3-1 shows how EPA estimated the affected population, ExPop(i)(s)(c), for CBG *i* in state *s* for cohort *c*.

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[12] 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.

[13] 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.

[14] Data is not available on the share of the fishing population that practices subsistence fishing. EPA assumed that 5% of people who fish practice subsistence fishing, based on the assumed 95th percentile fish consumption rate for this population (see U.S. EPA, 2011b).

[15] 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.

Equation 3-1. $\boldsymbol{ExPop(i)(s)(\mathrm{c})} = \boldsymbol{Pop(i)(\mathrm{c})} \times \%\boldsymbol{Fish(s)} \times \boldsymbol{A(i)} \times \boldsymbol{CaR(c)}$

Where:

Pop(i)(c) = Total CBG population in cohort c. Age and racial/ethnicity-specific populations in each CBG are based on data from the U.S. Census Bureau's 2010 Census. The Census data provides population numbers for each CBG broken out by age and racial/ethnic group separately. 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 the percentages to the population in each age group.

%Fish(s) = Fraction of people who live in households with anglers. To determine what percentage of the total population participates in fishing, EPA used region-specific U.S. Fish and Wildlife Service (U.S. FWS, 2011) estimates of the population 16 and older who fish.[16] EPA assumed that the share of households that includes anglers is equal to the fraction of people over 16 who are anglers.

A(i) = Adjustment for fish consumption advisories. EPA further adjusted the affected angler population to reflect the presence of FCAs, where applicable for a given reach. Based on EPA's review of studies documenting anglers' awareness of FCA and their behavioral responses to FCAs, 57.0 percent to 61.2 percent of anglers are aware of FCAs, and 71.6 percent to 76.1 percent of those who are aware ignore FCAs. Conservatively assuming that 61.2 percent of anglers are aware of applicable FCAs and that 71.6 percent of aware anglers ignore them, the number of anglers exposed to steam electric pollutants would be 17.4 percent lower for reaches with FCAs.[17] Therefore, for receiving reaches with FCAs, EPA reduced the affected populations by 17.4 percent.

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

Table 3-1 summarizes the population living within 50 miles of reaches affected by steam electric power plant discharges (see *Section 3.2.1* for a discussion of this distance buffer) and EPA's estimate of the population potentially exposed to the pollutants via consumption of recreationally-caught fish (based on 2010 population data and not adjusted for population growth during the analysis period). Of the total population, 14 percent live within 50 miles of an affected reach and participate in recreational and/or subsistence fishing, and 10 percent are potentially exposed to fish contaminated by steam electric pollutants.

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[16] The share of the population who fishes ranges from 9 percent in the Pacific region to 23 percent in the West North Central region. Other regions include the Middle Atlantic (11 percent), New England (12 percent), South Atlantic (13 percent), Mountain (15 percent), West South Central (16 percent), East North Central (16 percent), and East South Central (17 percent).

[17] This is calculated as 61.2 percent aware of advisories times 28.4 percent (100%-71.6%) who choose not to fish or otherwise don't eat fish caught in waterbodies affected by advisories.

Table 3-1: Summary of Potentially Affected Population Living within 50 Miles of Affected Reaches (baseline, as of 2010)

Total population	306,707,864
Total angler population[a]	42,710,492
Population potentially exposed to contaminated fish[b, c]	29,655,404

Source: U.S. EPA Analysis, 2015

a. Total population living within 50 miles of an affected reach times the state-specific share of the population who fishes based on U.S. FWS (2011; between 9% and 23%).

b. Total angler population adjusted to reflect lower fishing/consumption rates for reaches with fish consumption advisories and catch-and-release practices.

c. Analysis accounts for projected population growth so that the average affected population over the period of 2019 through 2042 is 21.3 percent higher than population in 2010 presented in the table, or 36 million people.

3.2 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 ADD and LADD consumed via the fish consumption pathway.

3.2.1 Fish Tissue Pollutant Concentrations

The set of reaches that may represent a source of contaminated fish for recreational anglers and subsistence fishers in each CBG depends on the typical travel distance anglers travel to fish. EPA assumed that anglers typically travel up to 50 miles to fish, using this distance to estimate the relevant fishing sites for the population of anglers in each CBG. See *Appendix F* for a sensitivity analysis using a travel distance of 100 miles. Based on data from the National Survey on Recreation and the Environment, about 80 percent of all water-based recreation occurs with 100 miles of the users' homes (Viscusi et al., 2008).

Anglers may have several fishable sites to choose from within 50 miles of travel. To account for the effect of substitute sites, EPA assumed that anglers are uniformly distributed among all the available fishing sites within 50 miles from the CBG (travel zone) and alternate their travels across all the sites. For each CBG, EPA identified all fishable COMIDs within 50 miles (where distance was determined based on the Pythagorean distance between the centroid of the CBG and the midpoint of the COMID) and the COMID length in miles

EPA then calculated, for each CBG, the reach-length weighted average fish tissue concentration of arsenic (As), mercury (Hg), and lead (Pb) based on all fishable sites within the 50 mile buffer. *Appendix D* describes the approach used to derive ambient water and fish tissue concentrations of steam electric pollutants in the baseline and under each of the regulatory options.

For each CBG, EPA then calculating the reach length ($Length_i$) weighted fish filet concentration (C_{Fish_Filet} *(CBG))* based on all fishable COMIDS within the 50 mile radius according to *Equation 3-2*:

Equation 3-2.
$$C_{Fish\_Filet_e}(CBG) = \frac{\sum_{i=1}^{n} C_{Fish\_Filet}(i) * Length_i}{\sum_{i=1}^{n} Length_i}$$

3.2.2 Average Daily Dose

Exposure to steam electric pollutants via fish consumption depends on the cohort-specific fish consumption rates. *Table 3-2* summarizes the fish consumption rates, expressed in daily grams per kilogram of body weight, according to the race/ethnicity and fishing mode. For more details on these fish consumption rates, see U.S. EPA (2015a).

Table 3-2: Summary of group-specific assumptions for human health benefit analysis[a]

Race/ Ethnicity	EA Cohort[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. U.S. EPA (2015a).

Equation 3-3 and *Equation 3-4* show the cohort- and CBG-specific calculation of the ADD and LADD based on fish tissue concentrations, consumption rates, and other assumptions about exposure duration and averaging periods, as shown below.

Equation 3-3. $$ADD(c)(i) = \frac{C_{Fish\_Filet} \quad (i) \times CR_{Fish}(c) \times F_{Fish}}{1000}$$

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_filet} (i) = average fish filet 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 3-2*.

F_{fish} = fraction of fish from contaminated source (percent; assumed value of 100%)

Equation 3-4. $$LADD = \frac{ADD \times ED \times EF}{AT \times 365}$$

Where:

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

$ADD(i)(c)$ = 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; assumed value of 350)

AT = averaging time (years; assumed value of 70)

EPA used the doses of steam electric pollutants from recreational caught fish thus obtained in its analysis of benefits associated with the various human health endpoints described below.

3.3 Benefits to Children from Reduced Lead Exposure

Lead is a highly toxic pollutant that can damage neurological, cardiovascular, and other major organ systems. In particular, elevated lead exposure may induce a number of adverse neurological effects in children, including hyperactivity, behavioral and attentional difficulties, delayed mental development, and motor and perceptual skill deficits (see U.S. EPA, 2015a). Elevated blood lead (PbB) concentrations in children may also result in metabolic effects such as impaired heme synthesis, anemia, and slowed growth (U.S. EPA, 1990; National Academy of Sciences, 1993; Kim et al. 1995). Severe lead poisoning may result in renal effects, seizures, impaired coordination, recurrent vomiting, coma, and acute lead encephalopathy, a potentially fatal condition (Piomelli et al., 1984; National Academy of Sciences, 1993; CDC, 2005). Studies have also found a relationship between lead exposure in expectant mothers and lower birth weight in newborns (Zhu et al., 2010; Bornschein et al., 1989; and Dietrich et al. 1987). Because of data limitations, EPA estimated only the benefits from reducing neurological and cognitive damages to pre-school (ages 0 to 7) children using the dose-response relationship for IQ decrements (Schwartz 1994).

EPA estimated benefits from reduced exposure to lead to preschool children using PbB as a biomarker of lead exposure. EPA first modeled PbB under the baseline and post-compliance scenarios, and then used a concentration-response relationship between PbB and IQ loss to estimate avoided IQ losses in the affected population of children and reduced incidences of extremely low IQ scores (less than 70, or two standard deviations below the mean). EPA calculated the monetary value of benefits to children 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 3.1* to estimate the population of pre-school children who live in recreational angler and subsistence fisher households and are potentially exposed to lead via consumption of contaminated fish tissue. Since this benefit category applies to children up to the seventh birthday only, EPA restricted the analysis to the relevant age cohorts of angler household members.

3.3.1 Methods

This analysis considers children who are born after implementation of the ELGs and live in recreational angler and subsistence fisher households. It relies on EPA's Integrated Exposure, Uptake, and Biokinetics (IEUBK) Model for Lead in Children (U.S. EPA, 2009c), which uses lead concentrations in a variety of media – including soil, dust, air, water, and diet – to estimate total exposure to lead for children in seven one-year age cohorts from birth through the seventh birthday. Based on this total exposure, the model generates a predicted geometric mean PbB for a population of children exposed to similar lead levels. The BCA report for the proposed ELG provides a more detailed description of the IEUBK model and describes EPA's application of the model to estimating benefits to pre-school children from reduced exposure to lead contaminated fish (U.S. EPA, 2013a).

For each CBG, EPA used the cohort-specific ADD based on *Equation 3-3*. Lead bioavailability and uptake after consumption varies 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 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-compliance scenarios. Note the IEUBK model processes daily intake to two decimal places (ug/day). For this analysis, this means that some of the change between the baseline and regulatory options is missed by using the model (*i.e.*, it does not capture very small changes), since the benefits are driven by very small changes across large populations.[18] As such, the benefits shown in this section are likely to underestimate the actual lead-related benefits to children arising from the ELG.

3.3.1.1 Estimating of Avoided IQ Point Losses

In a pooled data analysis, Lanphear et al. (2005; as cited in Agency for Toxic Substances and Disease Registry (ATSDR), 2007) found that the greatest IQ losses per 1 μg/dL occur at the lowest ranges of PbB. When the authors grouped IQ losses data for children with PbB below and above 7.5 μg/dL, they found that the IQ losses were 2.94 points per μg/dL for children with PbB concentrations below 7.5 μg/dL and 0.16 points per μg/d for children with PbB concentrations above 7.5 μg/dL.

Given the baseline PbB levels estimated using the IEUBK model (mean PbB of approximately 2.7 μg/dL), EPA used the dose-response factor of 2.94 points per μg/dL from Lanphear et al. to estimate changes in IQ losses between the baseline and post-compliance scenarios.[19] Comparing the baseline and post-compliance results provides the avoided IQ loss per child. Multiplying the result by the number of affected pre-school children yields the total increase 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 U.S. Census Bureau (2010) 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 final rule, 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 avoided IQ loss is thus an annual value (*i.e.*, it would apply to the cohort of children born each year after implementation).[20] *Equation 3-5* shows this calculation for the annual increase in total IQ points.

Equation 3-5.

$$\Delta \boldsymbol{IQ}(\boldsymbol{i})(\boldsymbol{c}) = \left(\Delta \boldsymbol{GM}(\boldsymbol{i})(\boldsymbol{c}) * \mathbf{CRF} * \left(\frac{\boldsymbol{ExCh}(\boldsymbol{i})}{\mathbf{7}}\right)\right)$$

Where:

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

$\Delta GM(i)(c)$ = the change in the average PbB in affected population of children (μg/dL) in cohort c in CBG i

CRF = concentration response function (2.94 IQ points lost per ug/dL increase in PbB)

$ExCh(i)$ = the number of affected children aged 0 to 7 for CBG i

The available economic literature provides little empirical data on society's overall WTP to avoid a decrease in children's IQ. To determine 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.

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[18] For example, the average intake across all affected children is reduced from 0.333 ug/kg BW/day under the baseline to 0.332 under Option D.

[19] See *Appendix F* for a sensitivity analysis using a log-linear concentration-response function.

[20] Dividing by seven undercounts overall benefits. Children from ages 1 to 7 are not accounted for in the base year of the analysis, although they are presumably affected by lead exposure.

Salkever (1995) and Schwartz (1994) estimate that a one point IQ reduction reduces expected lifetime earnings by 2.38 percent and 1.76 percent, respectively. Data from the U.S. Census Bureau for 2009 indicate that lifetime earnings are approximately $147,462 when discounting future earnings at 7 percent, and $656,737 when discounting future earnings at 3 percent.[21] The resulting estimated values of an IQ point are summarized in *Table 3-3*.

Table 3-3: Value of an IQ Point[a] (2013$)

Discount Rate	Assumed Reduction in Expected Lifetime Earnings (percent per IQ point)	
	1.76 percent/IQ point (Schwartz, 1994)	2.38 percent/IQ point (Salkever, 1995)
3 percent	$11,559	$15,630
7 percent	$2,559	$3,510

a. Values are not adjusted for the cost of education.

Decreased IQ also results in less education and, therefore, reduced education costs. Data from the National Center for Education Statistics (2014) indicate that the average expenditure per student in 2010/2011 was $12,600 (in 2013$). Schwartz (1994) and Salkever (1995) estimate that a one IQ point reduction results in 0.131 and 0.101 fewer education years, respectively; this represents lifetime cost savings between $377 and $970, discounting the avoided costs over 18 years. EPA subtracted these education costs from the value of lifetime earnings per IQ point in *Table 3-3.* Subtracting education costs is done for accounting purposes only and does not suggest that this is a desirable, positive outcome.

The value of an IQ point reduction adjusted for the avoided cost of education ranges between $2,107 (following Schwarz (1994) and discounting at 7 percent) to $14,883 (following Salkever (1995) and discounting at 3 percent). This effect represents only one component of society's WTP to avoid IQ decreases, and thus underestimates the total value of benefits to children from reduced exposure to lead.

3.3.1.2 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. EPA's IEUBK model can generate probabilities that a child would have a PbB in excess of a specific threshold.

EPA estimated the number of children that would have PbB above 20 µg/dL for each CBG under the baseline and each analyzed regulatory option. EPA assumed that 20 percent of children with PbB above 20 ug/dL would have IQs less than 70 and require compensatory education.[22] *Equation 3-6* shows the calculation of the number of children requiring compensatory education for each cohort and CBG. Summing across all cohorts and CBGs provides the total number of children who would require special education.

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[21] EPA updated lifetime earnings to 2013 dollars using the Consumer Price Index (2013=236.384; 2009 = 214.537).

[22] This assumption follows the methodology used by EPA in Economic and Environmental Benefits Analysis Document for the Final Effluent Limitations Guidelines and Standards for the Metal Products and Machinery Point Source Category (U.S. EPA, 2003).

Equation 3-6. $$\boldsymbol{CompEd(i)(c) = ExCh(i) * Pr20(i)(c) * S}$$

Where:

CompEd(i) = the number of children with PbB over 20 μg/dL and IQ less than 70 (who would need compensatory education) for cohort *c* in CBG *i*

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

Pr20(i) = the probability that a child's PbB is above 20 μg/dL for cohort *c* in CBG *i*

S = Share of children with PbB over 20 μg/dL that would have IQ scores less than 70 (20%)

The U.S. Department of Education (Chambers, et al., 2003) estimated that average annual expenditures for a student with mental retardation are approximately $8,484 higher than for an average student. Updating to 2013 dollars[23] yields annual costs of $16,075 per child. EPA assumed that children with IQ less than 70 would incur these additional costs each year for 12 years. Discounting future costs using a 3 percent discount rate yields a total compensatory education cost of approximately $164,806 per child with an IQ score less than 70 ($136,613 per child if using a 7 percent discount rate).

3.3.2 Results

Table 3-4 shows the benefits associated with avoided IQ losses from lead exposure via fish consumption, and *Table 3-5* shows the benefits associated with a reduced need for specialized education. The final BAT/PSES option will generate annualized benefits of $0.8 million to $1.1 million using a 3 percent discount rate, and $0.1 million to $0.2 million using a 7 percent discount rate.

Table 3-4: Estimated Benefits from Avoided IQ Losses for Children Exposed to Lead

Regulatory Option	Average Annual Number of Affected Children 0 to 7	Total Avoided IQ Losses, 2021 to 2042	Annualized Value of Avoided IQ Point Losses[a] (Millions 2013$)			
			3% Discount Rate		7% Discount Rate	
			Low Bound	High Bound	Low Bound	High Bound
Option A	3,326,127	853	$0.34	$0.48	$0.05	$0.08
Option B	3,326,127	853	$0.34	$0.48	$0.05	$0.08
Option C	3,326,127	1,285	$0.51	$0.72	$0.08	$0.12
Option D	3,326,127	1,985	$0.79	$1.11	$0.13	$0.19
Option E	3,326,127	1,985	$0.79	$1.11	$0.13	$0.19

Source: U.S. EPA Analysis, 2015

a. Low bound assumes that the loss of one IQ point results in the loss of 1.76% of lifetime earnings (following Schwartz, 1994); high bound assumes that the loss of one IQ point results in the loss of 2.38% of lifetime earnings (following Salkever, 1995).

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[23] Updated to 2013 dollars using the Consumer Price Index for Education (2013 = 224.521; 1999 = 107.0).

Table 3-5: Estimated Avoided Cost of Compensatory Education for Children with Blood Lead Concentrations above 20 μg/dL and IQ Less than 70

Regulatory Option	Number of Affected Children 0 to 7	Decrease in Number of Cases of IQ < 70, in 2021 to 2042	Avoided Annual Cost (Millions; 2013$)[a]	
			3% Discount Rate	7% Discount Rate
Option A	3,326,127	1	$0.00	$0.00
Option B	3,326,127	1	$0.00	$0.00
Option C	3,326,127	1	$0.01	$0.00
Option D	3,326,127	2	$0.01	$0.01
Option E	3,326,127	2	$0.01	$0.01

Source: U.S. EPA Analysis, 2015

a. “-“ indicates that a value was not estimated and “$0.00” indicates that avoided annual cost is less than $0.01 million.

3.4 Benefits to Adults from Reduced Lead Exposure

The public health literature suggests that a wide spectrum of adverse health outcomes can occur from lead exposure in people of all ages. For example, recent evidence has suggested that exposure to lead in adults can result in CVD impacts; specifically, increases in hypertension, coronary heart disease, CVD, and CVD-related mortality (National Toxicology Program, 2012; U.S. EPA, 2013b). EPA has developed and externally peer-reviewed concentration response functions for CVD-related mortality resulting from adult exposure to lead (Abt Associates, 2015 and U.S. EPA, 2015f). EPA is using these concentration response functions to estimate human health benefits from reduced adult exposure to lead following the implementation of the final ELGs.

3.4.1 Methods

This section summarizes EPA’s approach for estimating the benefits to human health due to reductions in adult exposure to lead following implementation of the final ELGs. EPA relied on two models to estimate baseline and post-compliance exposure for each population cohort:

- The first model estimates PbB in adults as a function of air-based background lead exposure and consumption of contaminated fish tissues.
- The second model is a population life table model that estimates the gains in life years due to decreased risk of CVD mortality from the PbB reductions.

EPA then aggregated the resulting cohort-specific gains in life expectancy to represent the total magnitude of the expected human health benefits for each ELG option. EPA estimated monetized benefits by applying a constant value per statistical life (VSL) to the estimated number of premature deaths avoided in each analysis year.

3.4.1.1 Modeling Blood Lead Concentrations in Adults

The Leggett model (Leggett, 1993), a physiologically-based pharmacokinetic model, has been used to estimate bone and blood lead levels in adults by U.S. EPA and others (California Office of Environmental Health Hazard Assessment (Cal OEHHA), 2013a, 2013b).[24] The model predicts PbB by explicitly modeling lead absorption, distribution, metabolism, and excretion for 21 body tissue compartments on a daily time step. Therefore, the model is able to address time-dependent conditions (*e.g.*, changing exposures through time).

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[24] EPA Office of Pollution Prevention and Toxics (OPPT) is using the Leggett+ model for the upcoming renovation and repair rule.

Since its original publication, the model has been updated and improved to better fit observed data. Most recently, the Cal OEHHA has published an updated version of the Leggett model, Leggett+, which they have used for occupational health standards in California. EPA implemented the updated model in the R programming language using publicly available documentation and MATLAB code (Cal OEHHA, 2013a, 2013b). The Agency modified the model inputs to more easily alter lead exposure due to contaminated fish consumption, and to reduce the complexity (and therefore computational time) of background exposure from air.[25] Internal model parameters with respect to the transit of lead through the 21 body tissues are unchanged. *Table 3-6* presents and describes parameters used to apply the Leggett+ model.

Table 3-6: Parameters Used to Apply the Leggett+ Model

Parameter	Units	Value	Notes
Age at Start of Exposure	Years	18	The Leggett+ model is parameterized to model PbB only for adults
Age in 2014	Years	25 – 65 in 10-year increments	Data used for all individuals within decadal cohort
Duration of Exposure to Contaminated Fish	Years	Within age cohort, number of years between 18 and year of ELG implementation.	Pre-2014 exposures limited to 27 years (based upon examination of model results). Pre-2014 exposure calculated as: Duration = Age in 2014 – 18.
Initial Blood Lead Concentration	µg/dL	1.5	CDC 2009; Schober 2006
Background Lead Intake	µg/day	1.8	Calculated to maintain PbB at 1.5 µg/dL with no fish exposure for a body mass of 74 kg (Cal OEHHA 2013a)
Body Mass	kg	Age Men Women 20s 82.5 71.4 30s 85.7 76.3 40s 88.0 76.3 50s 88.5 77.8 60s 88.2 75.6	Values from Table 8-24 of EPA (2011b). Values are held constant for all ages within each decade. Affects quantity of contaminated fish tissue consumed (see below).
Lead Intake from Contaminated Fish Tissue	mg/kg body mass / day	Average daily doses calculated as described in Section 3.2.2	Baseline (*i.e.*, no ELG) values used until 2021; thereafter, option-specific values.
Initial Tissue Compartment Parameters	Various	Various	Values used were obtained from CAL OEHHA (2013a).

EPA ran the models for several population cohorts defined by sex, age, exposure (recreational and subsistence fishers), and geography (215,460 CBGs) to characterize variability in the relevant population characteristics. The model was run on a daily time-step for each of the combinations of input parameters (6 scenarios [baseline + 5 ELG options)] x 2 sexes [male/female] x 215,460 CBGs x 2 exposure cohorts [recreational vs. subsistence fishing] x 5 age cohorts [20s – 60s, by decade]). Simulation duration included two separate

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[25] The Leggett+ model was designed to model airborne workplace exposure to air; in adapting the model to this analysis, EPA excised all parameters directly related to workplace exposure (including workplace airborne lead concentrations, breathing rate, transfer fraction of inhaled lead to blood, etc.) to improve model runtime. Background airborne ingestion remained consistent with the baseline Leggett+ model inputs.

components: exposures pre- and post-2015. Exposure occurring before 2015 (beginning at the age of 18 for each decadal age group) was run once for each combination of input parameters. These parameter values were then used as initial parameters for all model runs (baseline and the five ELG options) simulating exposure after 2015. Exposure prior to 2015 was limited to 27 years in duration, because inspection of model results suggested that additional lead accumulation in body tissues was minimal beyond 25 years. Consequently, simulations under no-ELG conditions ranged in duration from 34 years (for the 20s age cohort: 7 years of pre-2015 exposure plus 2015 – 2042, inclusive) to 54 years (for 50s and 60s age cohorts, 27 years of pre-2015 exposure plus 2015- 2042, inclusive), while the duration for all ELG-option simulations was 27 years (2015-2042, inclusive).

For each model run, EPA averaged forecasted PbB outputs within forecast year. *Figure 3-1* illustrates changes in PbB over time for two selected male subsistence fishing cohorts within a single CBG under the baseline and two of the regulatory options.

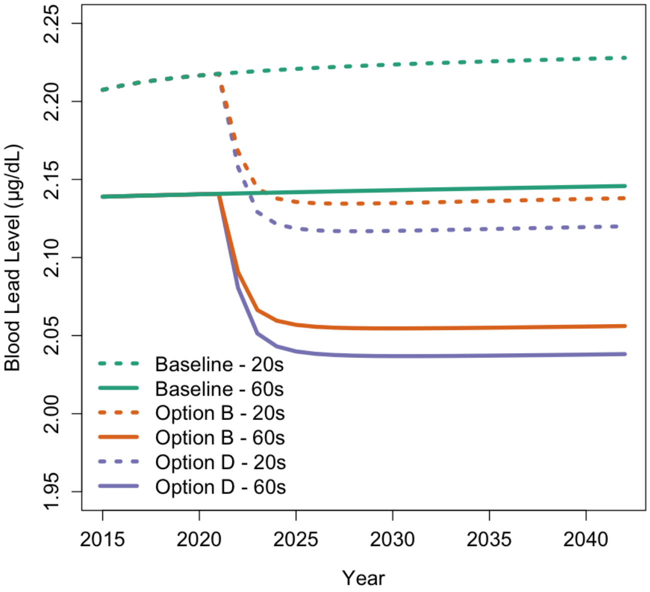

Figure 3-1: Example changes in PbB through time under baseline, option B, and option D for cohorts in the 20s and 60s (age as of 2014). Differences between cohorts are driven by differences in body mass. Example data represent modeled PbBs of male subsistence fishers residing in CBG 560419753004. The majority of cohorts nationwide experience a smaller reduction in PbB due to the rule.

Relative to baseline, PbB was reduced for approximately 1.1 percent of the simulated population under options A and B, 2.0 percent of simulations under option C, and 2.3 percent of simulated individuals under options D and E. The extent of the reductions followed the spatial distribution and magnitude of loading reductions across the options. When reductions did occur, they were typically small (*e.g.*, < 0.03 µg/dL in 2042 for options A – C, and < 0.08 µg/dL in 2042 for options D - E).

Relative to baseline, PbB was reduced by more than 1 percent of baseline – a decrease EPA considers to be a meaningful reduction level based upon CVD mortality rates – for between 0.03 percent to 1.18 percent of the simulated population under options A to E, respectively, with the final BAT/PSES (Option D) showing 1.18 percent of simulated individuals with a reduction of greater than 1 percent of baseline PbB.

3.4.1.2 Estimating Hazard Reduction under the Final ELGs

For each sex, single-year age, and exposure cohort (hereafter cohort), the analysis characterizes two basic survival analyses under the baseline and option scenarios: a death *hazard function* and a *survival function* (details of the analysis are provided in *Appendix E*).[26] To estimate changes in mortality following ELG implementation, EPA characterized:

1. the baseline CVD death hazard function;
2. the baseline non-CVD death hazard function; and
3. an option-specific CVD death hazard function.

The main source of data for hazard estimation in key simulation elements (1) and (2) above is a life table, a collection of statistics that shows age-specific probabilities of survival and fecundity.[27] EPA obtained life table data from two sources: the CDC's National Center for Health Statistics (Arias, 2014) and the CDC's Underlying Cause of Death Database (CDC 2012).[28] After obtaining all necessary data, EPA calculated age and sex- specific baseline hazards for CVD mortality; a sample of life table data used in calculations is presented in *Table 3-7*.

Table 3-7: Sample of Inputs for Age- and Sex-Specific Hazard Functions

Age	Sex	Proportion of Population	Mean Body Mass (kg)	CVD Rate (per 1,000)
20s	M	0.0875	82.5	0.072149
30s	M	0.0906	85.7	0.242882
40s	M	0.0977	88.0	0.833447
50s	M	0.0925	88.5	2.209863
60s	M	0.0630	88.2	4.633724
20s	F	0.0852	71.4	0.037076
30s	F	0.0909	76.3	0.123911
40s	F	0.0995	76.3	0.392972
50s	F	0.0973	77.8	0.940202
60s	F	0.0693	75.6	2.303575

Using CVD rates collected, EPA then calculated option-specific CVD death hazard functions based on the relationship between PbB and the CVD hazard ratio. To do this, EPA used a concentration-response function from a peer reviewed study which found an adjusted relative hazards of CVD mortality of 1.53 (1.21-1.94) per 3.4-fold increase in PbB (Menke et al. 2006).

3.4.1.3 Estimating Premature Deaths Avoided Over Multiple Years

The VSL is the marginal rate of substitution between wealth and mortality risk in a defined time period, usually taken to be one year. Therefore, the product of VSL and the estimated aggregate reduction in risk of

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[26] Collett (2003), pp. 10-12.

[27] An extensive discussion of life tables can be found in Shryock et al. (1980) Chapter 15.

[28] Database query parameters included: Dataset: Underlying Cause of Death, 1999-2010; Autopsy: All; Gender: Female, Male; ICD-10 Codes: I00-I99 (Diseases of the Circulatory System); Place of Death: All; Race: All; Single-year ages 20 – 100+, inclusive; Years: 2006-2010; States: All; Urbanization: All; Calculate Rates Per: 100,000; Rate Options: Default intercensal populations for years 2001-2009.

premature death represents the affected population's aggregate WTP to reduce its probability of death in one year. EPA estimated the benefits of multi-year mortality risk as the product of:

1. The reduction in initial age-specific mortality rate (*i.e.*, the proportion of people alive at exact age x, who will die before attaining exact age $x + 1$ in year t); and
2. The number of individuals surviving to the beginning of year t. This value is calculated as the initial cohort population size in 2015 multiplied by the probability that these individuals survive to age x, and are alive at the beginning of year t to enjoy the benefits of the year's mortality risk reduction.

It is important to note that WTP for a specific reduction in risk may depend on (i) the time of payment, (ii) the conditions under which the individual can save and borrow against future income, and (iii) whether the individual knows about the change in survival probability ahead of time (Hammitt 2007). The earlier an individual learns of the altered probability of survival, the earlier she "can adjust by reallocating her planned future consumption and risk-reducing expenditures." (Hammitt 2007).

3.4.2 Results

Table 3-8 summarizes the magnitude and economic value of human health benefits from reduced incidence of cardiovascular disease connected to adult lead exposure due to ELG implementation during the period 2019-2042. At a 3 percent discount rate, the final BAT/PSES (Option D) has annualized benefits of $12.8 million; the annualized benefits are $10.7 million at a 7 percent discount rate.

Table 3-8: Summary of Estimated Health Benefits due to Decreased Risk of CVD Mortality during 2019-2042 based on the Economic Value of Avoided Premature Mortality (VSL)

Regulatory Option	Aggregate Reduction in Risk of Premature Death	Annualized Benefits (millions 2013$)	
		3 Percent	7 Percent
Option A	10.7	$3.77	$3.14
Option B	10.7	$3.77	$3.14
Option C	23.6	$8.35	$6.97
Option D	36.2	$12.80	$10.68
Option E	36.2	$12.80	$10.68

Source: EPA Analysis, 2015

3.5 Benefits to Children from Reduced Mercury Exposure

Mercury can have a variety of adverse health effects on adults and children (see U.S. EPA, 2015a). The final ELGs are expected to reduce the discharge of mercury to surface waters by steam electric power plants and therefore provide a range of human health benefits. Due to data limitations, however, EPA estimated only the benefits from reduced 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 affected population described in *Section 3.1*. Because this analysis focuses only on infants born after implementation of the ELGs, EPA further limited the affected population by estimating the number of women between the ages of 15 and 42 potentially exposed to contaminated fish caught in the affected waterbodies, and multiplying the result by ethnicity-specific average fertility rates.[29] 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 2012 in the National Vital Statistics Report (Martin, et al., 2013). The fertility rate measures the number of births occurring per 1,000 women between the ages of 15-44 in a particular year. Fertility rates were highest for Hispanic women at 74.4, followed by African Americans at 65.0, Asian or Pacific Islanders at 62.2, Caucasians at 58.6, and Tribal/Other at 47.0.

3.5.1 Methods

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

To estimate maternal hair mercury concentrations based on the daily intake (see *Section 3.2.2*), 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 3-7* shows EPA’s calculation of the total annual IQ decrement for a given receiving reach.

Equation 3-7. $$\boldsymbol{IQL(i)(c) = InExPop(i) * MADD(i)(c) * (\frac{1}{Conv}) * DRF}$$

Where:

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

InExPop(i) = affected population of infants 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 ug/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 losses across all analyzed CBGs yields the total number of IQ points lost due to *in-utero* mercury exposure from maternal fish consumption under each analyzed regulatory option. The benefits of the ELGs are calculated as the reduction in IQ points lost between the baseline and modeled post-compliance conditions.

The available economic literature provides little empirical data on society’s overall WTP to avoid a decrease in children’s IQ. To determine 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 additional education. EPA used the same values of an IQ point presented in *Section 3.3.1*, which range from $2,107 to $14,883.

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[29] 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.

3.5.2 Results

Table 3-9 shows the estimated benefits of avoided IQ point losses for infants exposed to mercury in-utero. The final BAT/PSES option will generate annualized benefits of $2.9 million to $4.0 million at a 3 percent discount rate, and $0.5 million to $0.7 million at a 7 percent discount rate.

Table 3-9: Estimated Benefits from Avoided IQ Losses for Infants from Mercury Exposure

Regulatory Option	Number of Affected Infants per Year	Total Avoided IQ Losses, 2021 to 2042	Annualized Value of Avoided IQ Point Losses[a] (Millions 2013$)			
			3% Discount Rate		7% Discount Rate	
			Low Bound	High Bound	Low Bound	High Bound
Option A	418,953	3,239	$1.29	$1.81	$0.21	$0.31
Option B	418,953	3,311	$1.32	$1.85	$0.21	$0.32
Option C	418,953	6,001	$2.38	$3.35	$0.39	$0.58
Option D	418,953	7,219	$2.87	$4.03	$0.47	$0.69
Option E	418,953	7,898	$3.14	$4.41	$0.51	$0.76

Source: U.S. EPA Analysis, 2015

a. Low bound assumes that the loss of one IQ point results in the loss of 1.76 percent of lifetime earnings (following Schwartz, 1994); high bound assumes that the loss of one IQ point results in the loss of 2.38 percent of lifetime earnings (following Salkever, 1995).

3.6 Reduced Cancer Cases from Arsenic Exposure

Among steam electric pollutants analyzed in the EA, arsenic is the only confirmed carcinogen with a published dose response function (see U.S. EPA, 2010b).[30] EPA estimated the number of annual cancer cases associated with consumption of fish contaminated with arsenic from steam electric discharges under the baseline and each regulatory option. The reduction in the number of cancer cases from the baseline to post-compliance represents human health benefits attributable to the final ELGs.

3.6.1 Methods

EPA used the cohort-specific arsenic LADD (see *Section 3.2.2*) to calculate the total number of cancer cases for each cohort for each CBG under the baseline and each of the regulatory options, based on *Equation 3-8*.

Equation 3-8. $$\boldsymbol{CC(i)(c) = ExPop(i)(c) * CSF * LADD(i)(c)}$$

Where:

CC(i)(c) = the number of cancer cases for cohort *c* in CBG *i*

ExPop(i)(c) = the number of people affected for cohort *c* in CBG *i*

CSF = Cancer Slope Factor for skin cancer from arsenic [1.5 $(mg/kg\ BW/day)^{-1}$].

LADD(i)(c) = Lifetime Average Daily Dose of arsenic for cohort *c* in CBG *i* (mg/kg BW/day).

For this analysis, EPA used the current Integrated Risk Information System (IRIS) CSF, which is based on incidences of skin cancer. EPA is currently revising its cancer assessment of arsenic to reflect new data on

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[30] Although other pollutants, such as cadmium, are also likely to be carcinogenic (see U.S. Department of Health and Human Services (U.S. DHHS), 2008), EPA did not identify dose-response functions to quantify the effects of changes in these other pollutants.

internal cancers. It is possible that the revised combined (lung and bladder cancer) CSF would be higher (*e.g.*, the draft value is 25.7 per mg/kg BW/day), suggesting that the use of the current IRIS value may bias benefits downward.

Summing the number of cancer cases across all cohorts and all CBGs yields the total number of annual cancer cases under the baseline and each of the regulatory options. To estimate the number of avoided cancer cases, EPA subtracted the estimated number of cancer cases for each analyzed regulatory option from the estimated number of cancer cases under the baseline.

In the analysis of the proposed Steam Electric ELGs, EPA had used VSL to place a monetary value on avoiding a cancer case. This monetization approach inherently assumes that all cases would be fatal. Given that the majority of skin cancer cases (which are the basis for the health benefits arising from reduced arsenic exposure) are not fatal, this approach is likely to bias benefit estimates upward. For the analysis of the final rule, therefore, EPA revised the monetization approach to value skin cancer cases based on a COI approach.

Based on a literature review, EPA developed COI estimates for the skin cancer health endpoint associated with oral arsenic exposure (Abt Associates, 2014). The Agency found the following distribution of non-melanoma skin cancers associated with arsenic:

- Basal cell carcinoma: 15%;
- Invasive squamous cell carcinoma: 19%;
- Non-invasive squamous cell carcinoma: 58%; and
- Combined: 8%.

These types of skin cancers have very low fatality rates. Diagnosis involves medical histories, physical exams, and skin biopsies, while treatments consist of minor surgeries and periodic follow-up visits.

The COI estimates for skin cancers associated with arsenic include both direct medical expenditures and indirect opportunity costs. The direct medical costs were based on Medical Expenditure Panel Survey (MEPS) data on office-based provider visits and outpatient visits between 1996 and 2010, and represent the mean expenditures per patient.[31] Diagnosis and surgery are one-time costs, while follow-up visits are periodic for all years after the surgery, with frequency depending on the type of cancer. The other component of the cost of an illness is the opportunity cost – *i.e.*, the value of time lost during the illness. For non-melanoma skin cancer, EPA assumes that all patients in this analysis incur opportunity costs for diagnosis, surgery, and follow-up doctor visits. *Table 3-10* shows the total costs for different types of skin cancer.

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[31] Expenditures are for entire procedures; for example, expenditures for a surgery include the surgery itself as well as the associated hospital stay.

Table 3-10: Total Costs of Illness for Skin Cancer[a]

Type of Cost	Cost in First Year	Cost in Subsequent Years
Basal Cell Skin Cancer		
Medical care	$1,112	$307
Opportunity cost	$282	$39
Total cost for BCC	*$1,394*	*$347*
Non-invasive Squamous Cell Skin Cancer		
Medical care	$1,419	$266
Opportunity cost	$322	$34
Total cost for non-invasive SCC	*$1,741*	*$300*
Invasive Squamous Cell Skin Cancer		
Medical care	$3,020	$388
Opportunity cost	$460	$50
Total cost for invasive SCC	*$3,480*	*$439*

a. Updated to 2013$ using the consumer price index for medical care

Table 3-11 shows the weighted average skin cancer cost of illness estimate, based on the proportion of cases for each type of skin cancer. Overall, a skin cancer case from arsenic exposure results in costs of approximately $2,056 in the first year and $338 in the subsequent 14 years. Using a 3 percent discount rate, this equates to a $5,877 value of a skin cancer case, and using a 7 percent discount rate, the value is $5,015.

Table 3-11: Weighted Average Skin Cancer Cost of Illness[a]

Type	Proportion of Cases	COI (first year)	COI (subsequent years)[b]
Non-invasive squamous cell	58%	$1,741	$300
Invasive squamous cell	19%	$3,480	$439
Basal cell	15%	$1,394	$347
Combination[c]	8%	$2,205	$362
Total/Weighted Average	100%	$2,056	$338

a. updated to 2013$ using the consumer price index for medical care.

b. Assumes 14 subsequent years.

c. For "combination," EPA calculated COI based on the average of basal cell, invasive squamous cell, and non-invasive squamous cell cases.

A reduction in pollutant loadings does not immediately result in cessation of adverse health effects. There is a lag between the time when exposures are reduced and the time when a reduction in risk occurs. Additionally, there may be a latency period between the initial exposure and the onset of the illness. The latency period between low-dose arsenic exposure and skin cancer is unknown (Karagas et al., 2001; Shannon and Strayer, 1989), though some researchers postulate it could range from several years to decades (Karagas et al., 1998). U.S. EPA (2010b) notes that the cessation lag for skin cancer from arsenic is unknown, but that the cessation lag for internal cancers from arsenic may be longer than for skin cancer, ranging from 15 to 50 years. For this analysis, EPA assumed that cancer cases resulting from arsenic would not occur for ten years after exposure and discounted the value of avoided cancer cases by an additional ten years.

3.6.2 Results

Table 3-12 shows the estimated changes in incidence of cancer cases from exposure to arsenic in fish tissue under the ELGs and the annualized benefits calculated using 3 percent and 7 percent discount rates. Under both discount rates, annualized benefits are under $0.01 million.

Table 3-12: Annual Benefits from Reduced Cancer Cases due to Arsenic Exposure

Regulatory Option	Annual Affected Population	Reduced Cancer Cases, 2019 to 2042	Benefits (Millions 2013$)[a]	
			3% Discount	7% Discount
Option A	35,972,005	0.03	$0.00	$0.00
Option B	35,972,005	0.03	$0.00	$0.00
Option C	35,972,005	0.06	$0.00	$0.00
Option D	35,972,005	0.09	$0.00	$0.00
Option E	35,972,005	0.1	$0.00	$0.00

Source: U.S. EPA Analysis, 2015

a. "-" indicates that a value was not estimated and "$0.00" indicates that annual benefits are less than $0.01 million.

3.7 Total Monetized Human Health Benefits

Table 3-13 presents total monetized human health benefits for the final BAT/PSES (Option D) and alternate regulatory options. Using a 3 percent discount rate, benefits under Option D range from $16.5 million to $18.0 million ($11.3 million to $11.6 million using a 7 percent discount rate). Reduced lead exposure for adults and reduced mercury exposure for children represent the majority of total monetized human health benefits.

Table 3-13: Total Monetized Human Health Benefits for ELG Options (millions of 2013$)

Discount Rate	Option	Reduced Lead Exposure for Children[a]		Reduced Lead Exposure for Adults	Reduced Mercury Exposure for Children[a]		Reduced Cancer Cases from Arsenic[b]	Total[a]	
		Low	High		Low	High		Low	High
3%	A	$0.34	$0.48	$3.77	$1.29	$1.81	$0.00	$5.40	$6.06
	B	$0.34	$0.48	$3.77	$1.32	$1.85	$0.00	$5.43	$6.10
	C	$0.52	$0.73	$8.35	$2.38	$3.35	$0.00	$11.25	$12.43
	D	$0.80	$1.12	$12.80	$2.87	$4.03	$0.00	$16.47	$17.95
	E	$0.80	$1.12	$12.80	$3.14	$4.41	$0.00	$16.74	$18.33
7%	A	$0.05	$0.08	$3.14	$0.21	$0.31	$0.00	$3.40	$3.53
	B	$0.05	$0.08	$3.14	$0.21	$0.32	$0.00	$3.40	$3.54
	C	$0.08	$0.12	$6.97	$0.39	$0.58	$0.00	$7.44	$7.67
	D	$0.14	$0.20	$10.68	$0.47	$0.69	$0.00	$11.29	$11.57
	E	$0.14	$0.20	$10.68	$0.51	$0.76	$0.00	$11.33	$11.64

Source: U.S. EPA Analysis, 2015

a. Low bound assumes that the loss of one IQ point results in the loss of 1.76 percent of lifetime earnings (following Schwartz, 1994); high bound assumes that the loss of one IQ point results in the loss of 2.38 percent of lifetime earnings (following Salkever, 1995).

b. "$0.00" indicates that annual benefits are less than $0.01 million.

3.8 Additional Measures of Human Health Benefits

The benefits described above are only some of the human health effects expected to improve as a result of the final ELGs for which EPA was able to identify dose-response relationships. As noted in the introduction to this Chapter, pollutants in steam electric power plant discharges have been linked to additional adverse human health effects. To provide an additional measure of the potential health benefits of the final ELGs, EPA also estimated the expected reduction in the number of receiving reaches with pollutant concentrations in excess of human health-based AWQC. This analysis and its findings are not additive to the preceding analyses in this chapter, but represent another way of characterizing potential health benefits resulting from reduced exposure to steam electric pollutants. This analysis compares in-stream pollutant concentrations estimated for the baseline and each analyzed ELG option in receiving reaches and downstream reaches (see the EA; U.S. EPA, 2015a) to criteria established by EPA for protection of human health. EPA compared in-water concentrations of arsenic, copper, nickel, selenium, thallium, and zinc to EPA's national recommended water quality criteria protective of human health used by states and tribes (U.S. EPA, 2012b). Pollutant concentrations in excess of these values indicate potential risks to human health. For another four steam electric pollutants (cadmium, chromium, lead, and mercury) for which there are no recommended criteria, EPA instead compared concentrations to MCLs (U.S. EPA, 2012a).

Table 3-14 shows the results of this analysis. EPA estimates that in-stream concentrations of steam electric pollutants exceed human health criteria or MCLs for at least one pollutant in 3,673 reaches nationwide as a result of baseline steam electric pollutant discharges. EPA expects that the final BAT/PSES (Option D) will reduce the occurrence of concentrations in excess of human health-based criteria for 1,973 of the reaches, and eliminate all exceedances for 1,870 of those reaches. While Option D reduces concentrations in the remaining 103 reaches relative to the baseline levels, and thereby improves water quality in these reaches, the reductions are not sufficient to bring concentrations below the human health criteria or MCLs.

Table 3-14: Estimated Number of Reaches Exceeding Human Health Criteria for Steam Electric Pollutants

Regulatory Option	Number of Reaches with Steam Electric Pollutant[a] Concentrations Exceeding Human Health Criteria for at Least One Pollutant	Number of Reaches with Improved Water Quality, Relative to Baseline	
		Number of Reaches with Reduced Number of Exceedances[b]	Number of Reaches with All Exceedances Eliminated
Baseline	3,673	--	--
Option A	3,128	631	545
Option B	3,128	633	545
Option C	2,270	1,540	1,403
Option D	1,803	1,973	1,870
Option E	1,625	2,088	2,048

Source: U.S. EPA Analysis, 2015

a. Pollutants include arsenic, copper, nickel, selenium, thallium, zinc, cadmium, chromium, lead, and mercury.

b. The number of reaches with exceedances reduced includes those reaches where all exceedances are eliminated.

3.9 Implications of Revised Steam Electric Plant Loading Estimates

As described in *Section 1.4.3,* EPA revised its estimates of pollutant loadings in steam electric power plant discharges after completing the benefit analyses. The revisions affect baseline discharges of the three pollutants explicitly modeled to quantify and monetize human health benefits in this Chapter: lead, mercury, and arsenic. *Table 3-15* summarizes changes in loading estimates between the original loads used in estimating benefits in this Chapter and the revised loads. The table shows total industry loads of lead, mercury and arsenic in the baseline and under the final ELGs (Option D), as well as pollutant removals achieved by the final ELGs.

Table 3-15: Estimated Aggregate Changes in Pollutant Loadings for Lead, Mercury and Arsenic (Pounds per Year).

Pollutant	Baseline			Option D			Removal under Option D		
	Original Values	Revised Values	% Change	Original Values	Revised Values	% Change	Original Values	Revised Values	% Change
Lead	14,588	7,674	-47%	350	331	-5%	14,238	7,343	-48%
Mercury	1,176	992	-16%	31	31	-1%	1,145	961	-16%
Arsenic	22,219	20,138	-9%	1,483	1,480	0%	20,737	18,658	-10%

Source: U.S. EPA Analysis, 2015

As shown in *Table 3-15*, the revisions mainly reduced the baseline loadings of lead, mercury and arsenic, and had a smaller relative impact on loadings post-compliance. Because baseline pollutant loads are lower than previously estimated, EPA expects the adverse health effects estimated in the baseline to also be lower than previously calculated, which correspondingly reduces the incidence of adverse health effects avoided by implementing the final ELGs and therefore expected improvements from the final ELGs.

For several reasons — notably the fact that revisions do not affect all plants equally, exposure also depends on other point sources, and many model functions are not linear —it would be inappropriate to simply scale the monetized benefits based on the aggregate changes in loadings. While EPA cannot readily recalculate the benefits, the direction and magnitude of the change in pollutant removals in *Table 3-15* indicate that it is likely that revisions to the loadings affect benefit estimates and that new benefit estimates would be lower than presented in this Chapter. The magnitude of this reduction is, however, uncertain.

3.10 Limitations and Uncertainties

The analysis presented in this chapter does not include all possible human health benefits associated with post-compliance reductions 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 health benefits included in this analysis represent only a subset of the potential health benefits expected to result from the final rule.

Additionally, the methodologies and data used in the analysis of health benefits associated with reduced incidences of adverse health outcomes due to consumption of fish contaminated with steam electric pollutants involve limitations and uncertainties, that add to the limitations and uncertainties inherited from the EA analysis and data (see U.S. EPA, 2015a). *Table 3-16* summarizes the limitations and uncertainties and indicates the direction of the potential bias.

Table 3-16: Limitations and Uncertainties in the Analysis of Human Health Benefits

Uncertainty/Assumption	Effect on Benefits Estimate	Notes
The analysis is based loadings that were subsequently revised by EPA	Overestimate	Revised loadings of lead, mercury, and arsenic are lower than the loadings used to estimate benefits. The changes indicate that the incidence of adverse health effects are likely lower in the baseline, and therefore that improvements due to the ELGs may be correspondingly lower.
The analysis does not consider the suitability of alternate fishing sites.	Uncertain	Estimating the number of anglers fishing on receiving and downstream reaches based on the ratio of reach length to the total number of reach miles within the same 50-mile buffer area recognizes the effects of the quantity of competing fishing opportunities on the likelihood of fishing a given reach, but does not account for the differential quality of fishing sites. If the quality of substitute sites is distinctly worse or better (*e.g.*, some sites have better access or designated fishing areas), the estimated benefits may be overstated or understated.
Anglers are assumed to be distributed evenly (over the reach miles) over all available fishing sites within the 50-mile travel distance.	Uncertain	EPA assumed that all anglers travel up to 50 miles and distribute their visits over all fishable sites within the area. In fact, recreational anglers 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 the assumption on benefit estimates is uncertain since fewer/more anglers may be exposed to higher/lower fish tissue concentrations than assumed by EPA in the analysis.
The number of subsistence fishers was assumed to equal 5 percent of the total number of anglers fishing the affected reaches.	Uncertain	The magnitude of subsistence fishing in the United States or individual states is not known. Assuming 5 percent may understate or overstate the number of potentially affected subsistence fishers (and their households) overall, and ignores potential variability in subsistence rates across racial/ethnic groups.
EPA used a CSF for arsenic of 1.5 cases per mg/kg BW/day based on skin cancer only.	Uncertain	This is the current IRIS value and was based on incidences of skin cancer. EPA is currently revising its cancer assessment of arsenic to reflect new data on internal cancers.
There is a linear 0.18 point IQ loss for each 1 ppm increase in maternal hair mercury.	Uncertain	This dose-response function may over- or underestimate IQ impacts arising from mercury exposure if a linear function is not the best representation of the relationship between maternal body burden and IQ losses.

Table 3-16: Limitations and Uncertainties in the Analysis of Human Health Benefits

Uncertainty/Assumption	Effect on Benefits Estimate	Notes
For the mercury- and lead-related benefits analyses, EPA assumed that IQ losses are 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 acquisition and retention of information presented verbally and many motor skills (U.S. EPA, 2005). To the extent that these impacts create disadvantages for children exposed to mercury at current exposure levels or result in the absence of (or independent from) measurable IQ losses, this analysis may underestimate the benefits of the ELGs of reduced lead and mercury exposure.
The IEUBK model processes daily intake from "alternative sources" to 2 decimal places (ug/day).	Underestimate	Since the intakes are very small, some variation is missed by using the model (*i.e.*, it does not capture very small changes).
EPA did not quantify the benefits associated with reduced adult exposure to mercury.	Underestimate	The scientific literature suggests that exposure to mercury may have significant adverse health effects for adults; if measurable effects are occurring at current exposure levels, excluding the benefits of reduced adult exposure results in an underestimate of benefits.
EPA assumed constant body mass for all males and females in the adult Pb and As analyses	Uncertain	Male and female body mass estimates used in analyses are national estimates obtained from the CDC. The extent to which CBG-specific body masses varies will have an unknown effect on benefits
Uniform application of data from national life tables in adult Pb and As analyses	Uncertain	By applying national averages, EPA assumes that mortality rates of all modeled cohorts (specific to location, fishing cohort, etc.) do not differ from the national mortality experience. EPA also assumes that age-specific mortality rates are constant through time.
CVD-related benefits of reduced Pb exposure are not tracked for individuals younger than age 20 in 2014	Underestimate	Benefits accruing to younger individuals are not tracked because the Leggett+ model is unable to model PbBs in youth and adolescents.
EPA assumed no cessation lag for PbB effects	Uncertain	EPA assumed no time lag between changes in PbB and risk reductions. The accuracy of this assumption is unknown.
Concentration-response functions used in adult Pb and As analyses	Uncertain	The overall applicability of the concentration-response functions are subject to uncertainty. Generalized concentration-response functions are used to model age-specific hazard ratios.

4 Nonmarket Benefits from Water Quality Improvements

As discussed in the EA document (U.S. EPA, 2015a), heavy metals, nutrients, and other pollutants discharged by steam electric power plants have a wide range of effects on water resources located in the vicinity and 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. These second types of environmental goods and services are classified as “nonmarket”. The expected changes in the nonmarket values of the water resources affected by the final ELGs (hereafter nonmarket benefits) are additive to the market benefits (*e.g.*, avoided costs of producing various market goods and services) and benefits from improved groundwater quality estimated in other chapters (Freeman, 2003).

EPA’s approach to estimating the nonmarket benefits from water quality improvements resulting from the final ELGs involves 1) characterizing baseline and post-compliance water quality using a water quality index and 2) monetizing changes in the nonmarket value of affected water resources attributable to the final ELGs using a meta-analysis of surface water valuation studies that provide data on the public’s WTP for water quality improvements. The analysis accounts for improvements in water quality resulting from changes in nutrient, sediment, and metals concentrations in reaches affected by discharges from steam electric power plants.

4.1 Water Quality

To link water quality changes from reduced metal, nutrient and sediment discharges to effects on human uses and support for aquatic and terrestrial species habitat, EPA used a water quality index (WQI) which translates water quality measurements, gathered for multiple parameters that are indicative of various aspects of water quality, into a single numerical indicator.

The WQI provides the link between specific pollutant levels, as reflected in individual index parameters (*e.g.*, dissolved oxygen (DO) concentrations), and the presence of aquatic species and suitability for particular uses. The WQI value, which is measured on a scale from 0 to 100, reflects varying water quality, with 0 for poor quality and 100 for excellent.

The WQI used in this analysis is the same as was used for the proposed rule analysis.[32] The WQI includes the six parameters of the WQI previously used for the Final Construction and Development Rule – DO, biochemical oxygen demand (BOD), fecal coliform (FC), total nitrogen (TN), total phosphorus (TP), and total suspended solids (TSS) – and one additional subindex for metals, for a total of seven parameters.[33,34] As

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[32] The WQI modifies the WQI used by EPA in the Environmental Impact and Benefits Assessment for Final Effluent Guidelines and Standards for the Construction and Development Category (also referred to as the C&D rule; U.S. EPA, 2009a), which builds on McClelland (1974) and on the methodology developed by Dunnette (1979) and subsequently updated by Cude (2001) to better account for spatial and morphologic variability in the natural characteristics of streams. A more detailed discussion of the history of the WQI framework is found in Chapter 10 of the C&D report (U.S. EPA, 2009b).

[33] EPA modified the WQI for freshwater waterbodies from the C&D analysis to include metals. This was done by incorporating elements of the WQI developed by the Canadian Council of Ministers of the Environment

discussed in Chapter 4 of the EA document (U.S. EPA, 2015a), lotic systems such as rivers and streams, account for the vast majority (82 percent) of water bodies receiving direct discharges from steam electric power plants, with 183 of the 222 immediately receiving waters. Lentic freshwater systems such as lakes (with the exception of the Great Lakes), ponds, and reservoirs, represent 12 percent, the Great Lakes another 5 percent, and estuaries the remaining 1 percent. EPA focused the national level model on rivers/streams and lakes/ponds/reservoirs as the most common affected waterbodies. Because of the specific hydrodynamics and scale of the analysis required to appropriately model and quantify receiving water concentrations in the Great Lakes and estuary systems, EPA looked at the changes in pollutant loadings and impacts to these systems in selected case studies (see EA document for details; U.S. EPA, 2015a). EPA did not quantify the benefits to these systems, leading to an underestimate of the benefits discussed in this chapter.

4.1.1 WQI Calculation

Implementing the WQI methodology involves three key steps: 1) obtaining water quality levels for each of seven parameters included in the WQI; 2) transforming parameter levels to subindex values expressed on a common scale; and 3) aggregating the individual parameter subindices to obtain an overall WQI value that reflects waterbody conditions across the seven parameters. These steps are repeated to calculate the WQI value for the baseline (*i.e.*, in the absence of the final ELGs), and for each analyzed regulatory option.

The first step in the implementation of the WQI involves obtaining water quality levels for each parameter, and for each waterbody, under both baseline conditions and post-compliance conditions (see *Section 0*). Some parameter levels are field measurements while others are modeled values.

The second step involves transforming the parameter measurements into subindex values that express water quality conditions on a common scale of 0 to 100. EPA used the subindex transformation curves developed by Dunnette (1979) and Cude (2001) for the Oregon WQI for BOD, DO, and FC. For TSS, 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 the variability in geologic and other region-specific conditions, and to reflect the national context of the analysis. TSS, TN, and TP subindex curves were developed for each Level III ecoregion (U.S. EPA, 2009a) using baseline TSS, TN, and TP concentrations calculated in SPARROW at the E2RF1 reach level.[35,36,37] For each of the 85 Level III ecoregions intersected by the E2RF1 reach network, EPA derived the transformation curves by assigning a

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(CCME) wherein the index values are calculated based on the scope, frequency, and amplitude of exceedances of specified numeric thresholds (CCME, 2001).

[34] EPA analyzed changes to water quality resulting from the implementation of the final ELGs on receiving freshwater reaches. While steam electric plants also discharge to estuarine and coastal reaches, EPA did not estimate benefits from reducing pollutant loadings to these waterbodies due to the relatively small changes in concentrations expected.

[35] The SPARROW (SPAtially Referenced Regressions On Watershed attributes) model was developed by the United States Geological Survey (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

[36] EPA's E2RF1 (Enhanced River File Version 2.0) is a digital stream networks used in SPARROW models. This dataset extends over the continental United States and includes approximately 62,000 stream reaches.

[37] Following the approach EPA used for the C&D analysis, the selected data exclude outlier TSS concentrations, defined as values that exceed the 95th percentile based on the universe of all E2RF1 reaches modeled in SPARROW (U.S. EPA, 2009a). In the C&D analysis, the USGS and EPA had determined that these outlier values corresponded to headwater reaches and were an artifact of the model rather than expected concentrations.

score of 100 to the 25th percentile of the reach-level TSS concentrations 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 metals-specific subindex curve based on the number of Ambient Water Quality Criteria (AWQC) exceedances for metals in each waterbody. National freshwater chronic AWQC values are available for arsenic, cadmium, chromium, lead, mercury, nickel, selenium, and zinc. 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 metal 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 (see *Section 0* and *Appendix D* for details), and therefore any exceedance of an AWQC may indicate that ambient concentrations exceed AWQCs 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 AWQC then the water is impaired for that constituent and the level of exceedance is of secondary concern. Using this approach, the subindex curve for metals assigns the lowest subindex score of 0 to waters where exceedances are observed for all eight metals analyzed, and a maximum score of 100 to waters where there are no exceedances. Intermediate values are distributed evenly between 0 and 100.

Table 4-1 presents parameter-specific functions used for transforming water quality data into water quality subindices for freshwater waterbodies for the six traditional pollutants. *Table 4-2* presents the subindex values for metals. The equation parameters for each of the 85 ecoregion-specific TSS, TN, and TP subindex curves are provided in *Appendix G*.

Table 4-1: 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	N/A	mg/L	$100 \times \exp((DOsat - 100) \times -1.197\times10^{-2})$
275% < DO saturation			
DO	N/A	mg/L	10
Fecal Coliform (FC)			
FC	FC > 1,600	Lbs/100 mL	10
FC	50 < FC ≤ 1,600	Lbs/100 mL	$98 \times \exp((FC - 50) \times -9.9178\times10^{-4})$
FC	FC ≤ 50	Lbs/100 mL	98

Table 4-1: Freshwater Water Quality Subindices

Parameter	Concentrations	Concentration Unit	Subindex
Total Nitrogen (TN)[a]			
TN	$TN > TN_{10}$	mg/L	10
TN	$TN_{100} < TN \leq TN_{10}$	mg/L	a × exp(TN×b); where a and b are ecoregion-specific values in Appendix G
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 in Appendix G
TP	$TP \leq TP_{100}$	mg/L	100
Total Suspended Solids (TSS)[c]			
TSS	$TSS > TSS_{10}$	mg/L	10
TSS	$TSS_{100} < TSS \leq TSS_{10}$	mg/L	a × exp(TSS×b); where a and b are ecoregion-specific values in Appendix G
TSS	$\leq TSS_{100}$	mg/L	100
Biochemical Oxygen Demand, 5-day (BOD)			
BOD	BOD > 8	mg/L	10
BOD	BOD ≤ 8	mg/L	100 × exp(BOD × -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. TSS10 and TSS100 are ecoregion-specific TSS 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 using methodology in Cude (2001).

Table 4-2: Freshwater Water Quality Subindex for Heavy Metals

Number of Metals with AWQC Exceedances	Subindex
0	100.0
1	87.5
2	75.0
3	62.5
4	50.0
5	37.5
6	25.0
7	12.5
8	0.0

The final step in implementing the WQI involves combining the individual parameter subindices into a single WQI value that reflects the overall water quality across the parameters. EPA calculated the overall WQI for a given reach using a geometric mean function and assigned all WQ parameters an equal weight of 0.143 (1/7th of the overall score). Unweighted scores for individual metrics of a WQI have previously been used in Cude (2001), CCME (2001), and Carruthers and Wazniak (2003).

Equation 4-1 presents EPA's calculation of the overall WQI score.

$$WQI_r = \prod_{i=1}^{n} Q_i^{Wi}$$

Equation 4-1.

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)

Once an overall WQI value is calculated, it can be related to suitability for potential uses. Vaughan (1986) developed a water quality ladder (WQL) that can be used to indicate whether water quality is suitable for various human uses (*i.e.*, boating, rough fishing, game fishing, swimming, and drinking without treatment). Vaughan identified "minimally acceptable parameter concentration levels" for each of the five potential uses. Vaughan used a scale of zero to 10 instead of the WQI scale of zero to 100 to classify water quality based on its suitability for potential uses. Therefore, the WQI value corresponding to a given water quality use classification equals the WQL value multiplied by 10. *Table 4-3* presents water use classifications and the corresponding WQL and WQI values.

Table 4-3: Water Quality Classifications

Water Quality Classification	WQL Value	WQI Value
… drinking without treatment	9.5	95
… swimming	7.0	70
… game fishing	5.0	50
… rough fishing	4.5	45
… boating	2.5	25

Source: Vaughan (1986)

4.1.2 Sources of Data on Ambient Water Quality

EPA used the following data sources to obtain ambient concentrations for the seven parameters included in the WQI:

- Outputs from USGS's SPARROW models provided baseline and post-compliance concentrations of total nitrogen, total phosphorus, and total suspended solids. These calibrated national models are the same models previously used by EPA in the C&D rule analysis (U.S. EPA, 2009c). See Appendix D for further details.
- EPA estimated baseline and post-compliance metal concentrations using the water quality model component of EPA's *Risk-Screening Environmental Indicators* (RSEI) model (U.S. EPA, 2012c). EPA used estimates of metal loadings discharged from steam electric plants to directly receiving reaches under the baseline and the five analyzed options (see EA for discussion of directly receiving reaches; U.S. EPA, 2015a). EPA input the loadings from steam electric plants in the RSEI model to estimate the long-term average concentrations in directly receiving and downstream reaches. These

loadings are used to complement discharges already included in RSEI for other facilities that report to TRI. See *Appendix D* for details. The number of exceedances per waterbody (each reach) was calculated by comparing baseline and post-compliance concentrations with EPA's freshwater chronic aquatic life criteria values for each metal.[38] If the concentration was greater than the aquatic life criteria value for a given metal, EPA categorized the waterbody as having an AWQC exceedance for that metal. EPA then summed the total number of metals with AWQC exceedances (up to eight) for each waterbody under the baseline and under each analyzed regulatory option.

- The USGS National Water Information System (NWIS) provided concentration data for three parameters: 1) fecal coliform, 2) dissolved oxygen, and 3) biochemical oxygen demand. [39] EPA's Storage and Retrieval (STORET) data warehouse provided additional data on fecal coliform counts and biochemical oxygen demand where NWIS data was unavailable (U.S. EPA, 2008a).[40]

Note that the concentration data input into the WQI typically represent long-term average concentrations. *Table 4-4* summarizes the water quality modeling data used for estimating baseline and post-compliance metal, nutrient and sediment concentrations for reaches directly receiving steam electric plant discharge and for downstream reaches.

Table 4-4: Water Quality Modeling Data used in Calculating the Baseline and Policy Metal, Nutrient and Sediment Concentrations

Reach	Input Data	Water Quality Model	Model Output
Reaches directly receiving steam electric plant discharge and downstream reaches (18,622 NHD reaches total)	Baseline and policy metal loadings to inland reaches directly receiving steam electric plant discharges (U.S. EPA, 2015a). Metal loadings from other TRI dischargers in 2012.	Concentrations modeled in RSEI	In-steam metal concentrations at the NHD level
	Baseline and policy nutrient and sediment loadings to inland reaches directly receiving steam electric plant discharges (U.S. EPA, 2015a) Baseline values for other nutrient and sediment sources in inland reaches (*e.g.*, urban, agricultural and forested land, animal agriculture (nutrients), streambed (sediment), atmospheric deposition (nitrogen)).	Concentrations modeled in SPARROW	In-stream nutrient and sediment concentrations at the E2RF1 level

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[38] RSEI utilizes the USGS's National Hydrology Dataset (NHD) which 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. The NHD reaches in this analysis range from 0.003 miles to 9.11 miles in length.

[39] USGS's NWIS dataset 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/

[40] EPA's STORET (STOrage and RETrieval) Data Warehouse is a repository for water quality, biological, and physical water monitoring data. More information can be found at http://www.epa.gov/storet/

EPA used two different reach classification frameworks to assess in-stream water quality under the baseline and each of the regulatory options: the National Hydrography Dataset (NHD) network and the USGS's Enhanced River File 1 (E2RF1). Metal concentrations were estimated for reaches indexed to the NHD network. In contrast, the SPARROW, NWIS, and STORET data are available for reaches indexed to the E2RF1 network and to USGS's Hydrological Unit Code (HUC) watersheds. The WQI and benefits are ultimately calculated at the resolution of NHD reaches, but with adjustments made to data available only at the E2RF1 level to reflect differences in spatial scale. Thus, to reconcile the two levels of resolution, EPA mapped all modeled reaches from the E2RF1 to the NHD network using GIS and assigned the closest E2RF1 ID to each NHD reach. *Figure 4-1* illustrates the differences in scale between the E2RF1 network and the NHD network.

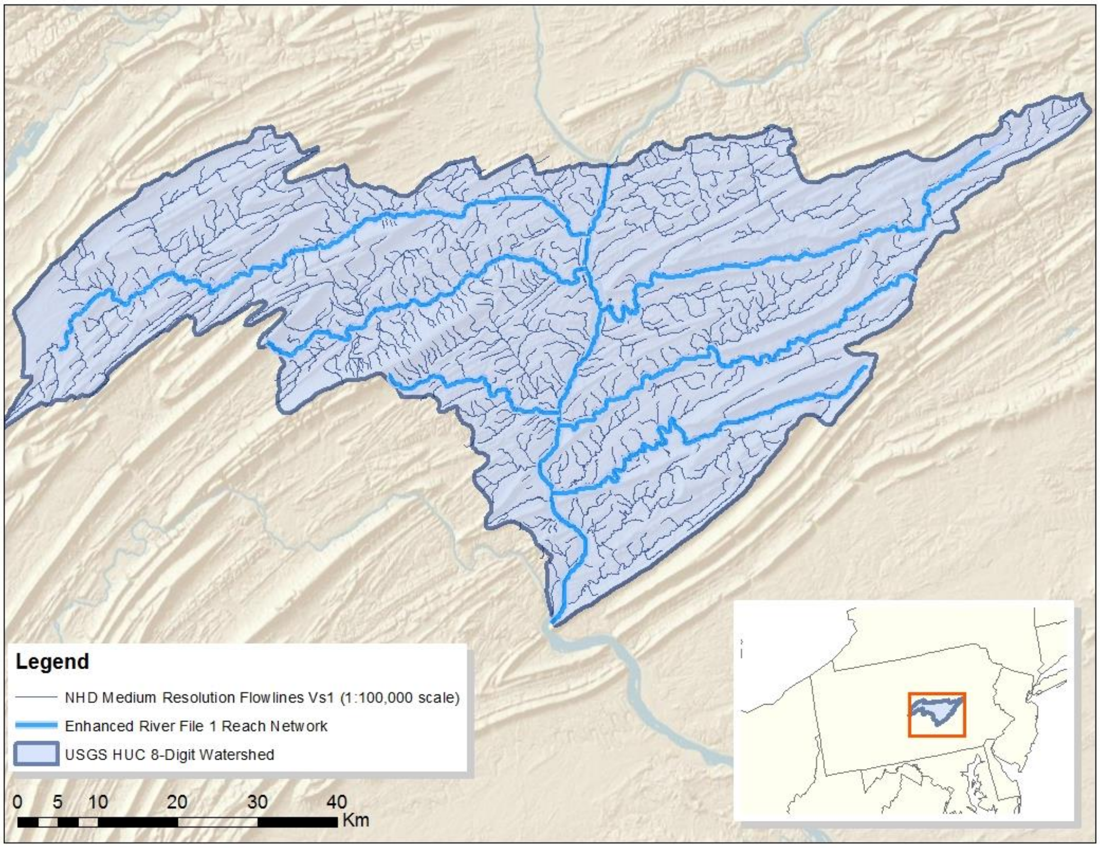

Figure 4-1: Comparison between the NHD and E2RF1 Network in a Single Watershed.

The water quality analysis included a total of 18,622 NHD reaches, totaling 27,421 miles, that are potentially affected by steam electric plants under baseline conditions. Baseline concentrations for all WQI parameters were available for over 95 percent of the potentially affected NHD reaches. EPA used a successive average approach to address the data gaps in WQI parameters not described above (*i.e.*, DO, BOD, fecal coliform) in the remaining inland reaches. The approach involves assigning the average of ambient concentrations for a WQI 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 (HUC8, HUC6, HUC4, and HUC2) to fill in all missing data.[41] This approach assumes that reaches located in the same watershed generally share similar characteristics. Using this estimation approach, EPA compiled baseline water quality data for all analyzed NHD reaches. Table *4-5* summarizes the data sources used to estimate baseline and post-compliance values by water quality parameters.

Table 4-5: Water Quality Data used in Calculating the Baseline and Policy WQI

Parameter	Baseline value	Post-compliance value
TN	From SPARROW output (baseline run) matched to NHD level	From SPARROW output (regulatory option run) matched to NHD level
TP	From SPARROW output (baseline run) matched to NHD level	From SPARROW output (regulatory option run) matched to NHD level
TSS	From SPARROW output (baseline run) matched to NHD level	From SPARROW output (regulatory option run) matched to NHD level
DO	Baseline value at the E2RF1 level matched to NHD level[a]	No change. Regulatory option value equal baseline value
BOD	Baseline value at the E2RF1 level matched to NHD level[a]	No change. Regulatory option value equal baseline value
Fecal Coliform	Baseline value at the E2RF1 level matched to NHD level[a]	No change. Regulatory option value equal baseline value
Metals	Baseline exceedances at NHD level based on RSEI model outputs	Regulatory option exceedances at NHD level based on RSEI model outputs.

a. Values based on STORET and NWIS data, complemented with data available for progressively larger geographical units (HUC8, HUC6, HUC4, and HUC2), as needed to fill in all missing data.

4.1.3 Baseline WQI

The water quality analysis included a total of 18,622 NHD reaches that are potentially affected by steam electric power generating plants under baseline conditions. Based on the estimated WQI value under the baseline scenario (WQI-BL), EPA categorized each of these 18,622 NHD reaches using five WQI ranges ($WQI < 25$, $25 \leq WQI < 45$, $45 \leq WQI < 50$, $50 \leq WQI < 70$, and $70 \leq WQI$). WQI values of less than 25 indicate that water is not suitable for boating (the recreational use with the lowest required WQI), whereas WQI values greater than 70 indicate that waters are swimmable (the recreational use with the highest required WQI).[42]

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

[42] EPA did not separately categorize waters where the WQI was greater than or equal to 90 (drinkable water), because the analysis did not examine other pollutants that may impact the drinkability of a water.

Table 4-6: Percentage of Potentially Affected Inland Reach Miles by WQI Classification: Baseline Scenario

Water Quality Classification	Baseline WQ	Number of Reaches	Percent of Potentially Affected Reaches	Number of Reach Miles	Percent of Potentially Affected Reach Miles
Unusable	WQI<25	0	0.0%	0	0.0%
Suitable for Boating	25≤WQI<45	677	3.6%	781	2.8%
Suitable for Rough Fishing	45≤WQI<50	649	3.5%	722	2.6%
Suitable for Game Fishing	50≤WQI<70	6,771	36.4%	10,187	37.2%
Suitable for Swimming	70≤WQI	10,525	56.5%	15,731	57.4%
Total		**18,622**	**100.0%**	**27,421**	**100.0%**

Source: U.S. EPA Analysis, 2015

4.1.4 Estimated Changes in Water Quality (ΔWQI) from the ELG Rule

To estimate benefits of water quality improvements expected to result from the final ELGs, EPA calculated the WQI for each analyzed regulatory option. As discussed in *Section 0*, EPA estimated changes in ambient concentrations of TN, TP and TSS using the USGS's SPARROW model and metal concentrations using the water quality component of the RSEI model. In calculating the post-compliance WQI (WQI-PC), the Agency used option-specific metal, TN, TP, and TSS concentrations. The estimated post-compliance metal, nutrient, and sediment concentrations reflect the expected reduction in pollutant discharges under each analyzed regulatory option. Although the final ELGs would also improve 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 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 final ELGs. *Table 4-7* presents water quality changes for all reaches. The water quality analysis included a total of 18,622 NHD reaches that are potentially affected by steam electric power generating plants under baseline conditions. Of these potentially affected reaches, 104 have fewer AWQC exceedances for metals under Option D. The combination of these reaches and reaches with reductions in nutrient or sediment concentrations modeled in SPARROW amount to a total of 13,229 unique NHD reaches, or 71 percent of reaches with ΔWQI > 0 under Option D, comprising a total of 19,573 reach miles, or 71 percent of all reach miles. Among other options analyzed, the largest number of reaches affected by the ELGs occurs under Option E. Under Option E, there are 13,537 inland reaches with ΔWQI > 0, totaling 20,300 miles. Note that the changes are based on annual average concentrations and represent changes expected after compliance with the final ELGs. As discussed in Section 1.5.3, the changes are assumed to start in 2021 and remain constant thereafter over the period of analysis through 2042.

Table 4-7: Water Quality Improvements from Final ELGs in All Benefiting Reaches

Change in WQI	Number of Inland Reaches	Percentage of Potentially Affected Inland Reaches (18,622 Reaches)	Reach Miles	Percentage of Potentially Affected Inland Reach Miles (27,421 Miles)
Option A				
ΔWQI = 0	13,843	74.34%	19,244	70.18%
0 < ΔWQI < 0.1	4,679	25.13%	7,998	29.17%
0.1 ≤ ΔWQI < 1	48	0.26%	99	0.36%
1 ≤ ΔWQI < 5	43	0.23%	72	0.26%
5 ≤ ΔWQI < 10	5	0.03%	3	0.01%
10 ≤ ΔWQI	4	0.02%	5	0.02%
Total	**18,622**	**100.00%**	**27,421**	**100.00%**
Option B				
ΔWQI = 0	9,928	53.31%	13,991	51.02%
0 < ΔWQI < 0.1	7,148	38.38%	11,115	40.53%
0.1 ≤ ΔWQI < 1	1,428	7.67%	2,165	7.89%
1 ≤ ΔWQI < 5	100	0.54%	121	0.44%
5 ≤ ΔWQI < 10	11	0.06%	10	0.04%
10 ≤ ΔWQI	7	0.04%	20	0.07%
Total	**18,622**	**100.00%**	**27,421**	**100.00%**
Option C				
ΔWQI = 0	7,922	42.54%	11,005	40.13%
0 < ΔWQI < 0.1	8,519	45.75%	13,122	47.85%
0.1 < ΔWQI < 1	2,011	10.80%	3,053	11.13%
1 ≤ ΔWQI <5	147	0.79%	202	0.74%
5 ≤ ΔWQI < 10	14	0.08%	19	0.07%
10 ≤ ΔWQI	9	0.05%	21	0.08%
Total	**18,622**	**100.00%**	**27,421**	**100.00%**
Option D				
ΔWQI = 0	5,393	28.96%	7,848	28.62%
0 < ΔWQI < 0.1	10,915	58.61%	16,066	58.59%
0.1 < ΔWQI < 1	2,111	11.34%	3,223	11.76%
1 ≤ ΔWQI < 5	178	0.96%	242	0.88%
5 ≤ ΔWQI < 10	13	0.07%	18	0.07%
10 ≤ ΔWQI	12	0.06%	23	0.09%
Total	**18,622**	**100.00%**	**27,421**	**100.00%**

Table 4-7: Water Quality Improvements from Final ELGs in All Benefiting Reaches

Change in WQI	Number of Inland Reaches	Percentage of Potentially Affected Inland Reaches (18,622 Reaches)	Reach Miles	Percentage of Potentially Affected Inland Reach Miles (27,421 Miles)
Option E				
ΔWQI = 0	5,085	27.31%	7,121	25.97%
0 < ΔWQI < 0.1	11,218	60.24%	16,777	61.18%
0.1 < ΔWQI < 1	2,106	11.31%	3,215	11.73%
1 ≤ ΔWQI < 5	187	1.00%	262	0.95%
5 ≤ ΔWQI < 10	13	0.07%	18	0.07%
10 ≤ ΔWQI	13	0.07%	28	0.10%
Total	**18,622**	**100.00%**	**27,421**	**100.00%**

Source: U.S. EPA Analysis, 2015

4.2 Methodology for Estimating WTP for Water Quality Improvements

To estimate the nonmarket benefits of the water quality improvements resulting from the final ELGs, EPA used results from a meta-analysis of stated preference studies summarized below and described in greater detail in *Appendix H*. This meta-analysis is a revised version of the 2009 meta-analysis used in the benefit-cost analysis of the proposed ELGs (U.S. EPA, 2013a). As described in the EPA report (U.S. EPA 2015e), EPA made a number of improvements to the meta-regression model. In particular, the revised meta-model satisfies the adding-up condition, a theoretically desirable property.[43] This condition ensures that if the model were used to estimate WTP for the cumulative water quality change resulting from a number of CWA regulations, the benefits estimates would be equal to the sum of benefits from using the model to estimate WTP for water quality changes separately for each rule. EPA used the revised meta-analysis to estimate the sum of use and non-use values for water quality improvements resulting from the final ELGs. In addition, EPA views the meta-analysis here as a work in progress and the current model is not the final product. Nonetheless, EPA views the results reported here as a clear improvement over the analysis used at proposal.

The meta-analysis is based on a meta-dataset of 51 stated preference studies, published between 1985 and 2011. Each of these studies used a stated preference approach to elicit survey respondents' willingness to pay for water quality improvements. EPA entered values for all existing variables in the meta-data for each study included in the meta-dataset. In addition to the study variables included in the 2009 meta-data, EPA developed and coded new variables (for all studies) that address gaps in the 2009 meta-data. While the 2009 meta-data largely relied on binary variables to distinguish broad categories of affected resources (*e.g.*, single vs. multiple rivers, regional freshwater), EPA developed new variables to capture geospatial factors including extent of sampled market, surveyed populations and affected resources. EPA report "*Meta-analysis of the Willingness-to-Pay for Water Quality Improvements"* provides detail on variable development and coding (U.S. EPA 2015e). The variables in the revised MRM fall into four general categories:

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[43] For a WTP function WTP (WQI_0, WQI_2, Y_0) to satisfy the adding-up property, it must meet the simple condition that WTP(WQI_0, WQI_1 , Y_0) + WTP(WQI_1, WQI_2 , Y_0 - WTP(WQI_0, WQI_1 , Y_0)) = WTP(WQI_0, WQI_2 , Y_0) for all possible values of baseline water quality (WQI_0), potential future water quality levels (WQI_1 and WQI_2), and baseline income (Y_0).

1. *Study methodology and year variables* characterize such features as the year in which a study was conducted, payment vehicle and elicitation formats, WTP estimation method, and publication type. These variables are included to explain differences in WTP across studies but are not expected to vary across benefit transfer for different policy applications.
2. *Region and surveyed populations variables* characterize such features as the geographical region within the United States in which the study was conducted, the average income of respondent households and the representation of users and nonusers within the survey sample.
3. *Sampled market and affected resource variables* characterize features such as the geospatial scale (or size) of affected waterbodies, the size of the market area over which populations were sampled, as well as land cover and the quantity of substitute waterbodies.
4. *Water quality (baseline and change) variables* characterize baseline conditions and the extent of the water quality change. To standardize the results across these studies, EPA expressed water quality (baseline and change) in each study using the 100-point WQI, if they did not already employ the WQI or WQL.

Using this meta-dataset, EPA then developed a meta-regression model that predicts how marginal WTP for water quality improvements depends on a variety of methodological, population, resource, and water quality change characteristics. In other words, the meta-regression model predicts the marginal WTP values that would be generated by a stated preference survey with a particular set of characteristics chosen to represent the water quality improvements and other specifics of the ELGs where possible, and best practices where not possible. EPA developed two versions of the meta-regression model. Model 1 is used to provide EPA’s central estimate of non-market benefits and Model 2 is used to develop a range of estimates to account for uncertainty in the resulting WTP values. The two models differ only in how they account for the magnitude of the water quality improvements presented to respondents in the original stated preference studies:

- Model 1 assumes that individuals’ marginal WTP depends on the level of water quality, but not on the magnitude of the water quality change specified in the survey. This restriction means that, the meta-model satisfies the adding-up condition, a theoretically desirable property.
- Model 2 allows marginal WTP to depend not only on the level of water quality but also on the magnitude of the water quality change specified in the survey. The model allows for the possibility that marginal WTP for improving from 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 final ELGs. When the water quality change is fixed at the mean of the meta-data, the predicted WTP is very close to the central estimate from Model 1.

EPA used the two meta-regression models in a benefit transfer approach that follows standard methods described by Johnston et al. (2005), Shrestha et al. (2007), and Rosenberger and Phipps (2007). The benefit transfer approach uses census block groups (CBGs) as the geographic unit of analysis.[44] The transfer approach involved projecting benefits in each CBG and year, based on the following general benefit function:

Equation 4-2. $$\ln(\boldsymbol{MWTP_{Y,B}}) = \boldsymbol{Intercept} + \sum(\boldsymbol{coefficient_i}) \times (\boldsymbol{independent\ variable\ value_i})$$

Where

$ln(MWTP_{Y,B})$ = The predicted natural log of marginal household WTP for a given year (*Y*) and CBG (*B*).

coefficient = A vector of variable coefficients from the meta-regression.

independent variable values = A vector of independent variable values. Variables include baseline water quality level ($WQI\text{-}BL_{Y,B}$) and expected water quality under the regulatory option ($WQI\text{-}PC_{Y,B}$) for a given year and CBG.

Here, $ln(MWTP_{Y,B})$ is the dependent variable in the meta-analysis—the log of approximated marginal WTP per household, in a given CBG *B* for water quality in a given year *Y*.[45] 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 at 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 will occur within a 2-hour drive from home. Because marginal WTP is assumed to depend, according to *Equation 4-2*, on both baseline water quality level ($WQI\text{-}BL_{Y,B}$) and expected water quality under the regulatory option ($WQI\text{-}PC_{Y,B}$), EPA estimated the marginal WTP for water quality improvements resulting from the final ELGs at the mid-point of the range over which water quality was changed, $WQI_{Y,B} = (1/2)(WQI\text{-}BL_{Y,B} + WQI\text{-}PC_{Y,B})$).

In this analysis, EPA estimated WTP for the households in each CBG for waters within a 100-mile radius of that CBG's centroid. EPA chose the 100 mile-radius because households are likely to be most familiar with waterbodies and their qualities within the 100 mile distance. However, this assumption may be an underestimate of the distance beyond which households have familiarity with and WTP for waterbodies affected by steam electric 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.[46] Total national WTP is calculated as the sum of estimated CBG-level WTP across all block groups that have at least one affected waterbody within 100 miles. Using this approach, EPA is unable to analyze the WTP for CBGs with no affected waters within 100 miles. *Appendix C* 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 improvements (*i.e.*, $WQI\text{-}PC_{Y,B}$), the scale of resource improvements relative to the size of the buffer and relative to available substitutes, the characteristics of surveyed populations (*e.g.*, users, nonusers), and other methodological

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[44] 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 .

[45] To satisfy the adding-up condition, as noted above, EPA normalized WTP values reported in the studies included in the meta-data so that the dependent variable is MWTP per WQI point. This 'average' marginal WTP value is an approximation of the MWTP value elicited in each survey scenario.

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

variables. For example, EPA assumed that household income (an independent variable) changes over time, resulting in household WTP values that vary by year.

Table 4-8 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 intercept, variable coefficients ($coefficient_i$) for the two models, and the corresponding independent variable names and assigned values. The meta-regression allows the Agency to forecast WTP based on assigned values for model variables that are chosen to represent a resource change in the final ELGs' policy context. EPA assigned a value to each model variable corresponding with theory, characteristics of the water resources, and sites affected by the final ELGs and the policy context. This follows general guidance from Bergstrom and Taylor (2006) that meta-analysis benefit transfer should incorporate theoretical expectations and structures, at least in a weak form.

In this instance, EPA assigned six study and methodology variables, (*thesis, volunt, nonparam, non_reviewed, lump_sum, and WTP_median*) a value of zero. One methodological variable, *outliers_trim*, was included with an assigned value of 1. Because the interpretation of the study year variable *(Lnyear)* is uncertain, EPA gave the variable a value of 3.0796, which is the 75th percentile of the year values in the meta-data. This value assignment reflects an equal probability that the variable represents a real time trend (in which case its value should be set to the most recent year of the analysis) and spurious effects (in which case its values should be set to the mean value from the meta-data). The choice experiment variable *(ce)* was set to 1 to reflect recent trends in the use of choice experiments within the environmental valuation literature. Model 2 includes an additional variable, water quality change (*ln_quality_ch*), which as discussed above allows the function to reflect differences in marginal WTP based on differences in the magnitude of changes presented to survey respondents when eliciting values. To ensure that the benefit transfer function satisfies the adding-up condition, this variable was treated as a demand curve shifter, similar to the methodological control variables, and held fixed for the benefit calculations. To estimate low and high values of WTP for water quality improvements resulting from the final ELGs, EPA estimated marginal WTP using two alternative settings of the *ln_quality* variable: ΔWQI = 5 units and ΔWQI = 50 units, which represent the low and high end of the range of values observed in the meta-data.

All but one of the region and surveyed population variables vary based on the characteristics of each CBG. For median household income, EPA used CBG-level median household income data from the U.S. Census 2010 (American Community Survey 5-year data) and used a stepwise autoregressive forecasting method to estimate future annual state level median household income. EPA set the variable *nonusers_only* to zero because water quality improvements 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). EPA set the variable r*iver* to 1 and *mult_type* to 0 because the analysis focuses only on rivers and streams. Other waterbody types (e.g., lakes and estuaries) are excluded from the analysis.

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 18,622 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 18,622 reaches that fall within the 100-mile buffer of the CBG. Spatial scale is held fixed across regulatory options. The variable corresponding to the sampled market (*ln_ar_ratio*) is set to the mean value across all CBGs included in the analysis of benefits from water quality improvements resulting from the final ELGs, and thus does not vary across affected CBGs.

Because data on specific recreational uses of the water resources affected by the final ELGs are not available, the recreational use variables (*swim_use*, *gamefish*, *boat_use*) are set to zero, which corresponds to "unspecified" or "all" recreational uses in the meta-data.[47] 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 improvement at affected resources within the 100-mile buffer of each CBG.

Table 4-8: Independent Variable Assignments for Surface Water Quality Meta-Analysis

Variable Type	Variable	Coefficient		Assigned Value	Explanation
		Model 1	Model 2		
Study Methodology and Year	intercept	-1.040	-6.14		
	Ce	0.377	0.423	1	Binary variable indicating that the study is a choice experiment. Set to one to reflect that choice experiments represent current state-of-art methods in stated preference literature.
	thesis	0.866	0.774	0	Binary variable indicating that the study is a thesis or dissertation. Set to zero because studies published in peer-reviewed journals are preferred.
	lnyear	-0.412	-0.5	3.0796	Natural log of the year in which the study was conducted (*i.e.*, data were collected), converted to an index by subtracting 1980. Set to the natural log of the 75th percentile of the year index value for studies in the metadata (21.7) to reflect uncertainty in the variable interpretation. If the variable represents a real time trend, the appropriate value should reflect the most recent year of the analysis. If it represents spurious effects, the values should reflect the mid-point from meta-data. Both interpretations are equally probable.
	volunt	-1.390	-1.184	0	Binary variable indicating that WTP was estimated using a payment vehicle described as voluntary as opposed to, for example, property taxes. Set to zero because hypothetical voluntary payment mechanisms are not incentive compatible (Mitchell and Carson 1989).
	outliers_trim	-0.367	-0.291	1	Binary variable indicating that outlier bids were excluded when estimating WTP. Set to one because WTP estimates that exclude outlier bids are preferable.
	nonparam	-0.408	-0.39	0	Binary variable indicating that regression analysis was not used to model WTP. Set to zero because use of the regression analysis to estimate WTP values is preferred.
	non_reviewed	-0.709	-0.871	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.

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

Table 4-8: Independent Variable Assignments for Surface Water Quality Meta-Analysis

Variable Type	Variable	Coefficient		Assigned Value	Explanation
		Model 1	Model 2		
	lump_sum	0.843	0.773	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.
	wtp_median	-0.161	-0.151	0	Binary variable indicating that the WTP measure from the study is the median. Set to zero because only average or mean WTP values in combination with the number of affected households will mathematically yield total benefits if the distribution of WTP is not perfectly symmetrical.
Region and Surveyed Population	*northeast*	1.180	0.593	Varies	Binary variable indicating that the affected population is located in a Northeast U.S. state, defined as ME, NH, VT, MA, RI, CT, and NY. Set based on the state in which the CBG is located.
	central	0.561	0.726	Varies	Binary variable indicating that the affected population is located in a Central U.S. state, defined as OH, MI, IN, IL, WI, MN, IA, MO, ND, SD, NE, KS, MT, WY, UT, and CO. Set based on the state in which the CBG is located.
	south	1.400	1.563	Varies	Binary variable indicating that the affected population is located in a Southern U.S. state, defined as NC, SC, GA, FL, KY, TN, MS, AL, AR, LA, OK, TX, and NM. Set based on the state in which the CBG is located.
	nonusers_only	-0.586	-0.54	0	Dummy variable indicating that the sampled population included nonusers only; the alternative case includes all households. Set to zero to estimate the total value for aquatic habitat improvements for all households, including users and nonusers.
	lnincome	0.333	0.96	Varies	Natural log of median household income values assigned separately for each CBG. Varies by year based on the estimated income growth in future years.
Sampled Market and Affected Resource	*mult_type*[a]	-0.827	-0.63	0	Binary variable indicating that multiple waterbody types are affected (*e.g.*, river and lakes). Set to zero because calculations are based exclusively on rivers.
	River	-0.079	-0.174	1	Binary variable indicating that rivers are affected. Set to one because calculations are based exclusively on stream miles. EPA did not estimate water quality changes for other waterbody types (*e.g.*, lakes and estuaries).
	swim_use	-0.234	-0.27	0	Binary variables that identify studies in which swimming, gamefish, and boating uses are specifically identified. Since data on specific recreational uses of the reaches affected by steam
	Gamefish	0.233	-0.01	0	

Table 4-8: Independent Variable Assignments for Surface Water Quality Meta-Analysis

Variable Type	Variable	Coefficient		Assigned Value	Explanation
		Model 1	Model 2		
	boat_use	-0.725	-0.32	0	electric plant discharges are not available, set to zero, which corresponds to all recreational uses.
	ln_ar_agr	-0.271	-0.413	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	-0.034	-0.057	1.238	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*). Set to the mean value from the CBG's with 100-mile buffers containing waters affected by the final ELGs.
	sub_proportion	1.100	0.607	Varies	The size of the affected resources 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 order(s) as the affected reaches within the buffer. Its value can range from 0 to 1.
Water Quality	*Q*	-0.015	-0.004	Varies	Because marginal WTP is assumed to depend on both baseline water quality and expected water quality under the regulatory option, this variable is set to the mid-point of the range of water quality changes due to the final ELGs, $WQI_{Y,B} = (1/2)(WQI\text{-}BL_{Y,B} + WQI\text{-}PC_{Y,B})$. Calculated as the length-weighted average WQI score for all potentially affected COMIDs within the 100-mile buffer of each CBG.
	lnquality_ch	NA	-0.746	ln(5) or ln(50)	*Ln_quality_ch* was set to the natural log of ΔWQI=5 or ΔWQI=50 for high and low estimates of the marginal WTP, respectively.

a. The meta-data includes six waterbody categories (1) river and stream, (2) lake, (3) all freshwater, (4) estuary, (5) river and lake, (6) salt pond/marshes, Variable *multi-type* takes on a value of 1 if the study focused on waterbody categories (3) and (6). EPA notes that the overall effect of this variable should be considered in conjunction with the regional dummies (*e.g.*, a study of the Lake Okeechobee basin in Florida) and that only eight percent of all observations in the meta-data fall in the multiple waterbody categories.

4.3 Total WTP for Water Quality Improvements

EPA estimated economic values of water quality improvements at the CBG level. For each block group, EPA multiplied the coefficient estimates for each variable, taken from meta-analysis results (*Table 4-8*, Coefficients: Model 1 and Model 2), by the variable levels calculated for each CBG or fixed at the levels indicated above (*Table 4-8*, column 4). The sum of these products represents the predicted natural log of marginal household WTP (*ln_MWTP*) for a representative household in each CBG, as indicated by *Table 4-8*.

Equation 4-3 provides the discount formula used to calculate household benefits for each CBG.

Equation 4-3.

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

where:

$HWTP_{Y,B}$ = Annual household WTP in 2013$ in year *Y* for households located in the CBG (*B*),

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

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

As summarized in *Table 4-9*, average annual household WTP estimates for the final ELGs (Option D) range from $0.32 on the low end (Model 2) to $1.77 on the high end (Model 2), with a central estimate of $0.35 (Model 1). The average is calculated based on the 84.5 million households affected by Option D. We note that the central estimate does not fall at the midpoint of the range, but instead represents the value from Model 1 which falls between the low and high bound estimates provided by Model 2.

Table 4-9: Household Willingness-to-Pay for Water Quality Improvements

Regulatory Option	Improving Reach Miles	Number of Affected Households (Millions)	Average Annual WTP Per Household (2013$)		
			Low	Central	High
Option A	8,177	30.3	$0.17	$0.20	$0.92
Option B	13,431	60.3	$0.28	$0.37	$1.58
Option C	16,417	67.9	$0.33	$0.46	$1.85
Option D	19,573	84.5	$0.32	$0.45	$1.77
Option E	20,300	94.3	$0.31	$0.45	$1.75

Source: U.S. EPA Analysis, 2015

To estimate total WTP (TWTP) for water quality improvements for each CBG, EPA multiplied the per-household WTP values for the estimated water quality improvement by the number of households within each block group in a given year. EPA then calculated annualized total WTP values for each CBG with both a 3 percent and 7 percent discount rate as shown below in *Equation 4-4*. As discussed in *Chapter 1*, benefits from water quality changes are estimated for all years between 2021 and 2042. For reaches directly receiving steam electric plant discharges, benefits are expected to begin accruing according to the technology implementation period of 2019 through 2023 described in Chapter 3 of the RIA (U.S. EPA, 2015b). Downstream reaches, however, can be affected not only by discharges from a given plant discharging directly to the reach, but also by any change in discharges from plants located upstream, which may have different compliance years. Therefore, for this analysis, EPA used a simplified assumption that all benefits begin accruing in 2021, which is the midpoint of the compliance period.

Equation 4-4.

$$TWTP_B = \left(\sum_{T=2021}^{2042} \frac{HWTP_{Y,B} \times HH_{Y,B}}{(1+i)^{Y-2015}}\right) \times \left(\frac{i \times (1+i)^n}{(1+i)^{n+1} - 1}\right)$$

where:

$TWTP_B$ = Total household WTP in 2013$ for households located in the CBG (*B*),

$HWTP_{Y,B}$ = Annual household WTP in 2013$ 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 (22 years)[48]

EPA generated annual household counts for each CBG through the period of analysis based on projected population growth following the method described in *Section 1.5.4*. *Table 4-10* presents the results for the 3 percent and 7 percent discount rates.

Table 4-10: Total Willingness-to-Pay for Water Quality Improvements

Regulatory Option	Number of Affected Households (Millions)	3% Discount Rate			7% Discount Rate		
		Low	Central	High	Low	Central	High
Option A	30.3	$4.2	$4.9	$23.4	$3.3	$3.9	$18.6
Option B	60.3	$15.0	$18.9	$83.7	$12.0	$15.2	$66.7
Option C	67.9	$19.6	$26.0	$109.4	$15.7	$20.9	$87.3
Option D	84.5	$23.2	$31.3	$129.5	$18.5	$25.1	$103.4
Option E	94.3	$25.1	$34.0	$140.0	$20.0	$27.3	$111.7

Source: U.S. EPA Analysis, 2015

EPA estimated that 19,573 reach miles would improve under the final ELGs. The total annualized benefits of water quality improvements resulting from reduced metal, nutrient and sediment discharges in these reaches range from $23.2 million to $129.5 million with a central estimate of $31.3 million using a 3 percent discount rate and $18.5 million to $103.4 million with a central estimate of $25.1 million using a 7 percent discount rate.

Readers may wonder why the central estimate is closer to the low end of the range than the high end. EPA tested several different functional forms for Model 2, and found that the model has the highest explanatory power (R-squared) when water quality change is included in logged form. This implies that water quality change has a nonlinear effect on MWTP. In particular, small initial increases in the scale of the water quality change scenario have a larger effect on MWTP than subsequent increases. This is the reason why the central estimate of MWTP (based on a water quality change scenario of approximately +20 units) is closer to the low MWTP estimate (based on a water quality change scenario of +50) than to the high MWTP estimate (based on a water quality change scenario of +5). In addition, when Model 2 is used in a benefits transfer application with a water quality change of +20, the mean of the meta-data, the results are very close to the results of

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[48] See Section 1.5.3 for detail on the period of analysis.

Model 1. This sensitivity analysis is included because a water quality change of +5 is closer to the size of water quality changes projected to result from the ELGs than the +20 analog to the central estimate, while the +50 represents the upper end of water quality changes in existing surveys (and the lower end of the sensitivity benefits range), for completeness.

In addition, EPA views its revisions to the meta-analysis employed here as a work in progress. As part of the revisions, EPA has identified some issues that require further analysis, and intends to continue this work after the Steam Electric ELGs are promulgated. EPA also intends to have the SAB review the results of that progress when it has reached a point of completion where SAB review is appropriate. In particular, EPA has identified the following issues to address: conducting additional robustness tests and cross validation, investigating model over-fitting, investigating whether a distance decay effect can be gleaned from the meta-data (to substitute for the 100-mile radius assumption used in the benefits transfer application here), and to consider employing Bayesian estimation techniques. However, EPA views the results presented here as a sufficient improvement over the results presented at proposal to warrant their inclusion in this report.

4.4 **Implications of Revised Steam Electric Plant Loading Estimates**

As described in *Section 1.4.3*, EPA revised its estimates of pollutant loadings in steam electric power plant discharges after completing the benefit analyses. The revisions affect baseline discharges of the several pollutants explicitly modeled to quantify and monetize the water quality improvement benefits in this Chapter: the eight metals, TN, TP and TSS. Changes in baseline metal loadings range from a 47 percent reduction (for lead) to a 1 percent increase (for selenium) while changes in TN, TP, and TSS loadings are all less than 1 percent. The overall effect of changes in TN, TP, and TSS loadings is likely to be trivial given the magnitude of loading reductions (i.e., less than 1 percent). Impacts of the revised metal loadings on the WQI score is difficult to assess since the score is not based on a continuous scale, but depends instead on whether the modeled instream concentrations metals exceed the relevant AWQCs. To the extent that baseline concentrations calculated based on the original loads exceed the relevant AWQCs only slightly, small reductions in these concentrations due to the revised loads could increase the baseline WQI score, all else being equal, and therefore reduce the magnitude of improvements attributable to the ELGs.

For several reasons — notably the fact that revisions do not affect all plants equally, the metals subindex score is based on counts of exceedances, and the model functions are not linear — it would be inappropriate to simply scale the monetized benefits based on the aggregate changes in loadings. However, comparison of the initial and revised baseline loads, on the one hand, and the ratios of modeled concentrations based on the initial loads to AWQCs, on the other hand, provides insight on the potential significance of the revisions on benefit estimates.

Table 4-11 summarizes changes in loading estimates between the original loads used in estimating benefits for Option D in this Chapter and the revised loads. The table shows total industry loads of the eight metals included in the WQI subindex, for the baseline and under the final ELGs (Option D).

Table 4-11: Estimated Aggregate Changes in Pollutant Loadings for Metals, Nutrients, and Suspended Solids.

Pollutant	Baseline Loadings			Option D		
	Initial	Revised	% Change	Initial	Revised	% Change
Arsenic	22,219	20,138	-9%	1,483	1,480	0%
Cadmium	10,925	8,289	-24%	636	630	-1%
Chromium (VI)	119	119	0%	0	0	0%
Lead	14,588	7,674	-47%	350	331	-5%
Mercury	1,176	992	-16%	31	31	-1%
Nickel	94,201	61,933	-34%	1,781	1,697	-5%
Selenium	112,999	114,533	1%	3,122	3,129	0%
Zinc	145,045	124,333	-14%	6,951	6,893	-1%
Total nitrogen	13,134,797	13,134,797	0%	69,969	70,285	0%
Total phosphorus	153,972	154,519	0%	31,630	31,667	0%
Total suspended solids	14,182,480	14,286,431	1%	1,661,665	1,665,345	0%

Source: U.S. EPA Analysis, 2015

While EPA cannot readily recalculate the benefits, the direction and relative magnitude of the change in pollutant removals in *Table 4-11* suggest there could be reaches where modeled concentrations would no longer exceed the applicable AWQS after revising the loadings. The changes are most significant for the baseline and are most likely to affect benefit estimates in instances where the concentrations were only slightly above the AWQC. However, review of baseline exceedances shows that, of the 1,023 exceedances present in the baseline (in 567 reaches), 774 exceedances result from instream concentrations being more than 1.5 times the relevant AWQC and 690 exceedances result from instream concentrations that are more than twice the AWQC. Instream concentrations would need to decline by at least 33 percent and 50 percent, respectively, to eliminate such baseline exceedances. Based on this data review, EPA concludes that the values presented in this Chapter based on the initial loadings provide reasonable insight into the water quality improvement benefits expected from the final ELGs.

Table 4-12: Number of Reaches with Baseline AWQC Exceedances Based on Initial Loadings.

Pollutant	Ratio of [baseline concentration]/[AWQC]		
	>1.0	>1.5	>2.0
Arsenic	167	128	124
Cadmium	151	100	75
Chromium (VI)	10	7	5
Lead	124	97	62
Mercury	17	11	7
Nickel	216	147	138
Selenium	91	68	47
Zinc	247	216	167

Source: U.S. EPA Analysis, 2015

4.5 Limitations and Uncertainties

Table 4-13 summarizes the limitations and uncertainties in the analysis of benefits associated with improved surface water quality and indicates the direction of any potential bias.

Table 4-13: Limitations and Uncertainties in the Analysis of Nonmarket Water Quality Benefits

Issue	Effect on Benefits Estimate	Notes
Revisions to pollutant loads used to estimate water quality improvements		
The analysis is based loadings that were subsequently revised by EPA	Overestimate	Revised loadings of parameters included in the WQI (notably the eight metals), are lower than the loadings used to estimate benefits. The changes indicate that number of exceedances of AWQCs may be lower in the baseline, and therefore the resulting improvements due to the ELGs may be lower. As discussed in Section 4.4, however, the magnitude of the overstatement may be small.
Limitations inherent to the meta-analysis model and benefit transfer		
Use of 100-mile buffer for calculating water quality benefits for each CBG	Underestimate	The distance between the surveyed households and the affected waterbodies is not well measured by any of the explanatory variables in the meta-regression model. EPA would expect values for water quality improvements 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.
Selection of the WQI parameter value for estimating low and high WTP values	Uncertain	EPA set ΔWQI to 5 and 50 units to estimate high and low benefit values based on Model 2. These values were based on the lowest and highest water quality changes included in the meta-data. To the extent that ΔWQI = 50 is significantly larger than the water quality expected from the final ELGs it is likely to significantly understate the estimated WTP value. ΔWQI = 5 is more consistent with the magnitude of water quality changes resulting from the final ELGs.
Whether potential hypothetical bias is present in underlying stated preference results	Uncertain	Following standard benefit transfer approaches, this analysis proceeds under the assumption that each source study provides a valid, unbiased estimate of the welfare measure under consideration (cf. Moeltner et al. 2007; Rosenberger and Phipps 2007). To minimize potential hypothetical bias underlying stated preference studies included in meta-data, EPA set independent variable values to reflect best benefit transfer practices.
Use of different water quality measures in the underlying meta-data	Uncertain	The estimation of WTP may be sensitive to differences in the environmental water quality measures across studies in the meta data. Studies that did not use the WQI were mapped to the WQI so a comparison could be made across studies. In preliminary model runs, EPA tested a dummy variable (WQI) that captures the effect of a study using (WQI=1) or not using (WQI=0) the WQI. The variable coefficient was not statistically different from zero, indicating no systematic bias in the mapping of studies that did not use the WQI.

Table 4-13: Limitations and Uncertainties in the Analysis of Nonmarket Water Quality Benefits

Issue	Effect on Benefits Estimate	Notes
Transfer error	Uncertain	Transfer error may occur when benefit estimates from a study site are adopted to forecast the benefits of a policy site. Rosenberger and Stanley (2006) define transfer error as the difference between the transferred and actual, generally unknown, value. While meta-analysis is fairly accurate when estimating benefit function, transfer error may be a problem in cases where the sample size is small. Meta-analyses have been shown to outperform other function-based transfer methods in many cases, but this result is not universal (Shrestha et al. 2007). This notwithstanding, results reviewed by Rosenberger and Phipps (2007) are "very promising" for the performance of meta-analytic benefit transfers relative to alternative transfer methods.
Use of the WQI to link water quality changes to effects on human uses and support for aquatic and terrestrial species		
Omission of lakes and estuaries from analysis of benefits from water quality improvements	Underestimate	12 percent of steam electric power generating plants discharge to the Great Lakes or estuaries. Due to limitations of the water quality models used in the analysis of the final ELGs, these waterbodies were excluded from the analysis. This omission is likely to underestimate benefits of water quality improvements from the final ELGs.
Changes in WQI reflect only reductions in metal, nutrient, and total suspended sediment concentrations	Uncertain	The estimated changes in WQI reflect only water quality improvements resulting directly from reductions in metal, nutrient and sediment concentrations. They do not include improvements in other water quality parameters (*e.g.*, BOD, dissolved oxygen) that are part of the WQI. If the omitted water quality parameters also improve, then the analysis underestimates the expected water quality changes.
In-stream metal concentrations are based only on loadings from steam electric power generating plants and other TRI dischargers	Uncertain	In-stream concentrations for heavy metals were estimated based on loadings from steam electric plant and other TRI dischargers only and, as a result, do not account for background concentrations of these pollutants from other sources, such as contaminated sediments, non-point sources, point sources that are not required to report to TRI, air deposition, etc. Not including other contributors to background metal concentrations in the analysis is likely to result in understatement of baseline concentrations of these pollutants and therefore of AWQC exceedances. The overall impact of this limitation on the estimated WTP for water quality improvement is uncertain but is expected to be small since the WTP function used in this analysis is most sensitive to the *change* in water quality.
Use of nonlinear subindex curves	Underestimate	The methodology used to translate in-stream sediment and nutrient concentrations into subindex scores 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 benefit in the analysis.

5 Impacts and Benefits to Threatened and Endangered Species

5.1 Introduction

Threatened and endangered (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. In many cases, T&E species are given special protection due to inherent vulnerabilities to habitat modification, disturbance, or other human impacts. This chapter examines the environmental impacts of steam electric power plant discharges on T&E species and the benefits associated with improvements resulting from the final ELGs and other regulatory options.

As described in the EA (U.S. EPA, 2015a), the chemical constituents of steam electric waste streams 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 psychological alterations in aquatic organisms (U.S. EPA, 2009d; Appendix H). 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 (Williams et al., 2001). 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. Consequently, steam electric power plant discharges may either lengthen recovery time, or hasten the demise of these species. For this reason, the final ELGs may have a significant impact on T&E species populations.

From an economic perspective, T&E species affected by steam electric power plant discharges may have both use and nonuse values. However, given the protected nature of T&E species and the fact that use activities generally constitute take, which is illegal unless permitted, the majority of T&E species do not have direct uses, the majority of the economic value for T&E species comes from nonuse values. Species-specific estimates of nonuse values held for the protection of T&E species can be most accurately derived by primary research using stated preference techniques. However, the cost, administrative burden, and time required to develop primary research estimates to value effects of the final rule on T&E species are beyond the schedule and resources available to EPA for this rulemaking. As an alternative, EPA used a benefit transfer approach that relies on information from existing studies (U.S. EPA, 2010c).

In this chapter, EPA explores the current status of major freshwater taxa, identifies the extent to which the final ELGs can be expected to benefit species protected by the Endangered Species Act (ESA), and applies economic valuation studies to these T&E species to estimate WTP for these benefits.

5.2 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; Williams et al., 1989; Williams et al., 1993; Taylor et al., 1996; Taylor et al., 2007; Jelks et al., 2008). Overall, aquatic species are disproportionately imperiled relative to terrestrial species. For example, while 39 percent of freshwater and diadromous fish species (Jelks et al., 2008) are classified as T&E, a similar status review found that only 7 percent of North American bird and mammal species are currently imperiled (Wilcove and Master, 2005).

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 (Williams, Johnson et al. 1989) and 1979 (Deacon et al., 1979), respectively. Despite recent conservation efforts, including the listing of several species under the 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 strikingly 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 ranged from a low of 22 percent for Centrarchidae (sunfishes) to a high of 61 percent for Salmonidae (salmon) (Jelks et al., 2008).

5.3 T&E Species Affected by the Final ELGs

To assess the potential effects of the final ELGs on T&E species, EPA constructed databases to determine which species are found in waters expected to improve due to a reduction in pollutant discharge from steam electric power plants. Notably, these databases exclude all species considered threatened or endangered by scientific organizations [*e.g.*, the American Fisheries Society (Williams et al., 1993; Taylor et al., 2007; Jelks et al., 2008)] but not protected by the ESA. These databases allowed EPA to estimate the potential for adverse impacts of steam electric power plant discharges on T&E species, as well as benefits associated with the final ELGs.

5.3.1 Identifying T&E Species Potentially Affected by the Final ELGs

To estimate the effects of the final ELGs on T&E species, all affected species must first be identified. EPA identified all species currently listed or in consideration for listing under the ESA using the U.S. FWS Environmental Conservation Online System (U.S. FWS, 2014a). Whenever possible, EPA obtained the geographical distribution of T&E species in geographic information system (GIS) format as polygon (shape) files, line files (for inhabitants of small creeks and rivers) and as a subset of geodatabase files. Data sources include U.S. FWS (2014b), the National Oceanic and Atmospheric Administration's (NOAA's) Office of Response and Restoration (NOAA, 2010), NatureServe (NatureServe, 2014), and NOAA National Marine Fisheries Service (NMFS, 2014a; NMFS, 2014b; NMFS, 2014c). For several freshwater species, geographic ranges were available only as 6-digit HUCs (NatureServe, 2014; U.S. FWS, 2014b). For these species, EPA created GIS data layers using a GIS HUC database obtained from the USGS (Steeves and Nebert, 1994).

To determine the probability that individual T&E species could benefit from the final ELGs, EPA compiled data on locations of steam electric power plants and receiving waterbodies. The Agency used plant and outfall coordinates it had obtained through its 2010 Questionnaire for the Steam Electric Power Generating Effluent Guidelines (the industry survey) and georeferenced these coordinates to waterbodies (see EA for details; U.S. EPA, 2015a). The result of this analysis consists of the NHD Plus (COMIDs) identifiers of waterbodies that receive discharges from steam electric power plants and indicators of water quality under the baseline and each analyzed regulatory option. EPA queried these data to identify "affected areas" as those habitats where 1) receiving waters do not meet water quality metrics recognized to cause harm in organisms under baseline conditions; and 2) receiving waters exceed water quality metrics under the most stringent regulatory option EPA analyzed (Option E). EPA used these data in ArcGIS to determine the T&E species with habitat extents overlapping the affected areas.

EPA constructed a screening database using the spatial data. This database included all T&E species whose habitat overlaps those waterbodies receiving effluent discharges from steam electric power plants. A buffer of 500 m was chosen when constructing this database to account for any minor errors in outfall location and habitat maps.

After identifying T&E species potentially affected by the final ELGs, EPA classified the species on the basis of their vulnerability to changes in water quality. Species were classified as follows:

- *High 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.
- *Low vulnerability* – species whose habitats overlap bodies of water, but whose life history traits and food sources are terrestrial.

Life history data used to classify species were obtained from a wide variety of sources (Froese and Pauly, 2009; NatureServe, 2014; Alaska Fisheries Science Center (AFSC), 2010; Atlantic States Marine Fisheries Commission (ASMFC), 2010; Northeast Fisheries Science Center (NEFSC), 2010; Pacific Islands Fisheries Science Center (PIFSC), 2010a; PIFSC, 2010b; Southeast Fisheries Science Center (SEFSC), 2010; Southwest Fisheries Science Center (SWFSC), 2010; U.S. FWS, 2010).

The results of the spatial analysis and vulnerability classification process (as described above) are presented in *Table 5-1*. *Appendix I* lists all T&E species potentially affected by the final ELGs.

Table 5-1: T&E Species with Habitat Occurring within Waterbodies Affected by Steam Electric Power Plants

Species Group	**Species Vulnerability**			**Species Count**
	Low	**Moderate**	**High**	
Amphibians	0	2	2	4
Arachnids	4	0	0	4
Birds	9	2	1	12
Clams	0	0	33	33
Crustaceans	0	1	1	2
Fishes	0	0	17	17
Insects	10	2	1	13
Mammals	17	4	1	22
Reptiles	3	1	5	9
Snails	8	0	14	22
Total	**51**	**12**	**75**	**138**

Source: U.S. EPA Analysis, 2015

For the purposes of estimating benefits, EPA excluded all species with low and moderate vulnerability potentials based upon life history traits. For all species with high potential vulnerability, EPA conducted further analyses to identify those species likely to be affected by the final ELGs, rather than all species whose life histories make them vulnerable. High vulnerability species meeting the following criteria were removed from further consideration:

- Species presumed to be extinct, including those not collected for a minimum of 30 years (*e.g.*, *Noturus trautmani*).
- Endemic species living in waterbodies (*e.g.*, isolated headwaters, natural springs) unlikely to be affected by steam electric power plant discharges (*e.g.*, *Gambusia georgei*).
- Species protected by the ESA whose recovery plans i) do not include pollution or water quality issues as factors preventing recovery, and ii) identify habitat destruction (due to damming, stream channelization, water impoundments, wetland drainage, etc.) as a primary factor preventing recovery (*e.g.*, *Erimystax cahni*).
- Listings due to non-native species introductions and/or hybridization with native or non-native congeners (*e.g.*, *Oncorhynchus clarki somias*)
- Listings where water quality issues are identified as the primary issue preventing recovery, but where a specific industry or entity not within the scope of the final ELGs is identified as the culprit. (*e.g.*, *Erimystax cahni* due to siltation from coal mining activity).
- Species about which very little is known, including geographic distribution.

After eliminating the T&E species meeting these criteria, EPA identified a total of 15 species whose recovery may be enhanced by the final ELGs.

5.3.2 Estimating Benefits of T&E Species Improvements from the Final ELGs

The final ELGs have the potential to positively affect the recovery trajectory for 15 T&E species. For each of these species, EPA estimated the magnitude of potential benefits by identifying inhabited waterbodies likely to meet AWQC for aquatic life as a consequence of the final ELGs and comparing these areas to the overall area of habitat occupied by T&E species.

First, for each T&E species affected by steam electric power plant discharges, EPA examined water quality in each of the waterbodies inhabited by each T&E species under baseline conditions, and under conditions projected to exist following implementation of the final ELGs. For each analyzed regulatory option, EPA identified waterbodies that 1) do not meet AWQC for wildlife under baseline conditions, but 2) have no wildlife AWQC exceedances following implementation of the final ELGs. For 11 species, there were no waterbodies that met these conditions, leaving three T&E fish species and one salamander species in nine states that may experience increases in population growth rates as a result of the final ELGs (*Table 5-2*).

Table 5-2: T&E Species Whose Recovery May Benefit from the Final ELGs

Species	Common Name	State(s)
Acipenser brevirostrum	Shortnose Sturgeon	MD, SC
Cryptobranchus alleganiensis	Hellbender salamander	IL, KY, MO, OH, PA
Etheostoma chermocki	Vermilion darter	AL
Etheostoma etowahae	Etowah darter	GA

Source: U.S. EPA Analysis, 2015

EPA did not identify data sufficient to explicitly model population growth rates as a function of water quality for any of these species. Therefore, to estimate proportionate population increases as a result of the final ELGs, EPA identified the fraction of inhabited waterbodies that meet wildlife AWQC as a consequence of the final ELGs. This fraction was used to estimate relative population changes in estimating the WTP for T&E species recovery.

5.4 Estimating WTP for T&E Species Population Increases

5.4.1 Economic Valuation Methods

For several reasons, it is difficult to estimate the benefits of improving T&E species habitats resulting from the final ELGs. First, data required to estimate the response of T&E populations to improved habitats are rarely available. Second, the contribution of T&E species to ecosystem stability, ecosystem function, and life history remains relatively unknown. Third, much of the wildlife economic literature focuses on commercial and recreational benefits that are not relevant for many protected species (*i.e.*, use values).There is a paucity of economic data focused on the benefits of preserving habitat for T&E species because nonuse values comprise the principal source of benefit estimates for most T&E species.

Analysis of nonuse benefits for T&E species affected by changes in pollutant discharges from steam electric power plants stemming from the final ELGs involves the following two steps: 1) quantifying the impacts of pollutant discharges from steam electric power plants on T&E species and estimating the change in these impacts as a consequence of reducing steam electric discharges; and 2) estimating an economic value of improving T&E habitats and populations as a consequence of the final ELGs.

Benefit transfer involves extrapolating existing estimates of nonmarket values to the policy sites that potentially differ from the original analytical situation in terms of geographic locations or affected species. Ideally, the resource in question (*i.e.*, T&E species), policy variables (change in species status, recovery interval, population size, etc.), and the geographic location and benefitting population (*i.e.,* defined human population) are identical. Such a match rarely occurs. Despite differences in these variables, however, a benefit transfer approach can provide useful insights into the social benefits gained by reducing impacts on T&E species.

5.4.2 Estimating WTP for Improved Protection of T&E Species

To estimate the potential economic values of increased T&E species populations affected by the final ELGs, EPA used a benefit transfer approach based on a meta-analysis of 31 stated preference studies eliciting WTP for changes in T&E populations (Richardson and Loomis, 2009). This meta-analysis is based on studies conducted in the United States that valued threatened, rare, or endangered fish, bird, reptile, or mammal species. Because the underlying meta-data does not contain amphibian valuation studies, EPA was unable to monetize any benefits for potential population increases of Hellbender salamander as a result of the final ELGs. *Equation 5-1* contains the estimated WTP equation from the Richardson and Loomis (2009) paper that EPA used to monetize potential population increases resulting from the final ELGs.

Equation 5-1. $ln\, WTP\ (2006\$) = -153.231 + 0.870\, ln\, CHANGESIZE + 1.256\, VISITOR + 1.020\, FISH + 0.772 MARINE + 0.826\, BIRD - 0.603\, ln\, RESPONSERATE + 2.767\, CONJOINT + 1.024\, CHARISMATIC - 0.903\, MAIL + 0.078\, STUDYYEAR.$

Table 5-3 lists the assigned variable values and definitions used in estimating per household WTP for improved protection of T&E species resulting from the final ELGs.

Table 5-3: Independent Variable Assignments for the T&E Meta-Regression

Variable	Description	Value	Explanation
Intercept	Intercept	-153.231	-
ln ChangeSize	Natural log of percentage change in the population of the species of interest	Varies	Log of percentage change in fish population
Visitor	Dummy variable indicating if survey respondents are visitors rather than full-time residents	0	Primary beneficiaries are expected to be full-time state residents
Fish	Dummy variable indicating population increases for fish species	1	Only freshwater T&E fish species are expected to be affected
Marine	Dummy variable indicating population increases for marine mammals	0	
Bird	Dummy variable indicating population increases for bird	0	
Charismatic	Dummy variable indicating a charismatic species	Varies	Sturgeon species are considered charismatic; minnow species are not
Conjoint	Dummy variable indicating conjoint method surveys	0	Default value from Richardson and Loomis (2009) as only one underlying meta-study used conjoint analysis; the rest were CV studies
ln ResponseRate	Natural log of the survey response rate	3.912	Mean value from Richardson and Loomis (2009) following the Johnston et al. (2006) approach where values for methodological attributes are set at mean values from the metadata
Mail	Indicates mail surveys	0.851	
StudyYear	Year of study	1992	

Source: U.S. EPA Analysis, 2015

EPA does not currently have either species-specific estimates of the population effects of the final ELGs or population models to estimate future population changes for the affected T&E species due to improved aquatic habitat conditions. In the absence of such estimates, EPA used best professional judgment to assign a range of potential improvements in the T&E populations based on the expected reductions in AWQC exceedances under the post-compliance scenario. To estimate total population increases as a result of each analyzed regulatory option, EPA assumed minimal increases in population size of 0.5, 1, or 1.5 percent. EPA then weighted these population growth estimates within states by the proportion of reaches used by T&E species expected to meet wildlife-based AWQC under each option. The natural log of these weighted population growth estimates under each scenario was used to assign a value to the *ChangeSize* parameter estimate. EPA used the approach described in Johnston et al. (2006) and assigned mean study values from Richardson and Loomis (2009) for the methodological variables (*ln ResponseRate, Mail, and StudyYear).*

Although it could not find published literature to support dose-response relationships for any of the species assessed or any other numerical estimates of benefit that might occur to T&E species because of the rule, EPA believes that its low (0.5 percent), medium (1.0 percent) and high (1.5 percent) estimates of population growth for T&E species (occurring within affected reaches exceeding AWQC at baseline) because of the final ELG are reasonable. This is because of the high number of species filtered from further assessment (as described in Sections 5.3.1 and 5.3.2, only four species met all criteria for inclusion), because population increases were estimated to occur only in reaches meeting AWQC because of the rule (the majority of habitat used by T&E species assessed meets AWQC at baseline), and because few individuals must be saved to attain these growth estimates. For example, consider a T&E species with a state-level population of 10,000 individuals (reasonable for threatened species, likely an over-estimate for endangered species and endemic species), residing in 10 reaches - only one of which does not meet AWQC criteria at baseline (but does under rule options), and a population growth rate of 0 in the baseline. This species would achieve EPA's low, medium and high population increases if the ELG results in one fewer premature mortality every 5 years (low growth) and approximately one fewer premature mortality every 1.5 years (high growth) between 2019 and 2042. This low level of effect needed to meet growth assumptions, when combined with known effects of wildlife living in areas with poor water quality, make this level of population increase reasonable.

Because population growth was assessed at the state level, EPA was unable to attribute benefits to a specific steam electric power plant and therefore to account for the timing of benefits based on the assumed control technology implementation year. EPA assumed that benefits begin accruing in 2021 for all states. This year is the midpoint of the period of 2019 through 2023 when plants are assumed to implement control technologies to comply with the revised effluent limits and standards.

For each state, EPA estimated household WTP for improved protection of T&E species resulting from the final ELGs using *Equation 5-1* and the independent variable assignments presented in Table 5-3. EPA estimated total annual benefits for the years between 2021 and 2042 by multiplying household WTP by the number of households in each state for a given year. EPA then calculated the value of benefits for each year and the annualized total WTP values for each state using 3 percent and 7 percent discount rates.

5.5 **Results**

Table 5-4 presents the annualized total benefits calculated using discount rates of 3 percent and 7 percent. The monetized benefits to T&E species of Option D are concentrated in two states: Alabama (AL) and Georgia (GA). The annualized benefits of Option D are $0.02 million for the medium population increase using a 3 percent discount rate.

Table 5-4: Estimated Annualized Benefits to T&E Species from WQ Improvements (Millions 2013$)[a,b]

Discount Rate	State	Option A			Option B			Option C			Option D			Option E		
		Low	Medium	High	Low	Medium	High	Low	Medium	High	Low	Medium	High	Low	Medium	High
3%	AL	<$0.01	<$0.01	<$0.01	<$0.01	<$0.01	<$0.01	<$0.01	<$0.01	<$0.01	<$0.01	<$0.01	<$0.01	<$0.01	<$0.01	<$0.01
	GA	<$0.01	$0.01	$0.01	<$0.01	$0.01	$0.01	<$0.01	$0.01	$0.01	<$0.01	$0.01	$0.01	<$0.01	$0.01	$0.01
	MD	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	<$0.01	$0.01	$0.01	<$0.01	$0.01	$0.01	<$0.01	$0.01	$0.01
	SC	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	<$0.01	<$0.01	$0.01	<$0.01	<$0.01	$0.01	<$0.01	<$0.01	$0.01
	Total	**$0.01**	**$0.01**	**$0.02**	**$0.01**	**$0.01**	**$0.02**	**$0.01**	**$0.02**	**$0.03**	**$0.01**	**$0.02**	**$0.03**	**$0.01**	**$0.02**	**$0.03**
7%	AL	<$0.01	<$0.01	<$0.01	<$0.01	<$0.01	<$0.01	<$0.01	<$0.01	<$0.01	<$0.01	<$0.01	<$0.01	<$0.01	<$0.01	<$0.01
	GA	<$0.01	$0.01	$0.01	<$0.01	$0.01	$0.01	<$0.01	$0.01	$0.01	<$0.01	$0.01	$0.01	<$0.01	$0.01	$0.01
	MD	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	<$0.01	$0.01	$0.01	<$0.01	$0.01	$0.01	<$0.01	$0.01	$0.01
	SC	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	<$0.01	<$0.01	<$0.01	<$0.01	<$0.01	<$0.01	<$0.01	<$0.01	<$0.01
	Total	**$0.01**	**$0.01**	**$0.01**	**$0.01**	**$0.01**	**$0.01**	**$0.01**	**$0.02**	**$0.03**	**$0.01**	**$0.02**	**$0.03**	**$0.01**	**$0.02**	**$0.03**

Source: U.S. EPA Analysis, 2015

5.6 Implications of Revised Steam Electric Plant Loading Estimates

As described in *Section 1.4.3*, EPA revised its estimates of pollutant loadings in steam electric power plant discharges after completing the benefit analyses. The revisions affect baseline discharges of several pollutants with wildlife AWQC exceedances. For several reasons — notably the fact that revisions do not affect all plants equally, and that species vulnerability to steam electric pollutants is determined based on threshold effects — it would be inappropriate to simply scale the monetized benefits based on the aggregate changes in loadings. The impacts of the loading revisions on estimated benefits to E&T specifies may be similar to that discussed in Section 4.4 for water quality improvement benefits.

5.7 Limitations and Uncertainties

Table 5-5 summarizes the caveats, omissions, biases, and uncertainties known to affect EPA's estimates of the benefits to T&E species and indicates the direction of the potential bias.

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

Issue	Effect on Benefits Estimate	Notes
The analysis is based loadings that were subsequently revised by EPA	Overestimate	Revised loadings are lower than the loadings used to estimate benefits. The changes indicate that number of exceedances of AWQCs may be lower in the baseline, and therefore the improvements resulting from the ELGs may be lower. As discussed in Section 4.4, however, the magnitude of the overstatement may be small.
Change in T&E populations due to the effect of steam electric ELGs is uncertain	Uncertain	Data necessary to quantitatively estimate population changes are unavailable. Therefore, EPA used best professional judgment to assess reasonable changes in T&E populations. Actual effects of the final rule may be larger or smaller than projected changes in the population of T&E species assumed in this analysis.
Only those T&E species listed as threatened or endangered on the Endangered Species Act are included in the analysis	Underestimate	The databases used to estimate benefits to T&E species exclude all species considered threatened or endangered by scientific organizations but not protected by the ESA. The magnitude of the underestimate is likely to be significant, since the proportion of imperiled fish and mussel species is high (*e.g.*, Jelks et al 2008, Taylor et al 2007).
Benefit estimates do not include monetized values for potential population increases in Hellbender salamander (*Cryptobranchus alleganiensis a)*	Underestimate	It is likely that population increases in *Cryptobranchus alleganiensis* have value to the public. In addition to bequest, altruistic, and existence values, salamanders may have aesthetic or cultural values. Salamanders also provide beneficial ecological services through indirect biotic control of species diversity and ecosystem processes, connection of energy and matter between aquatic and terrestrial landscapes, contributing to soil dynamics, and providing available stores of energy and nutrients for tertiary consumers (David and Welsh 2004).

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

Issue	Effect on Benefits Estimate	Notes
Benefit estimates are likely to include only a subset of species that may be affected	Underestimate	EPA did not consider species for which water quality was not listed as an important factor to species recovery. Because water quality issues may be important to species recovery even if not listed explicitly in species recovery plans this analysis may omit species that are likely to benefit from the final ELG.
Benefit transfer introduces uncertainties	Uncertain	Value may over- or understate true WTP values (See *Section 4* for more details).
Ecological roles filled by T&E species	Underestimate	WTP values are unlikely to include changes to food-webs and ecosystem stability as a consequence of the restoration (or loss) of T&E species.
Overlap between WTP estimates for T&E species and the WTP estimates for improvements in water quality	Overestimate	There may be some overlap between WTP estimates for T&E species and the WTP estimates for improvements in water quality because WTP values for improvements in water quality may inherently include benefits to T&E species. However, none of the studies in EPA's meta-analysis of WTP for water quality improvements specifically mentioned or otherwise prompted respondents to include benefits to T&E species populations (see *Chapter 4*); therefore, any overlap is likely to be minimal.
WTP estimates do not take into account possible substitution for effects for similar species.	Overestimate	WTP estimates may be affected by the availability of related species (Hoehn and Loomis, 1993), however Kahneman and Knetsch (1992) argue that substitution effects may not apply to the values associated with endangered species, because their uniqueness is the essence of their existence value.

6 Benefits from Avoided Impoundment Failures

EPA has promulgated several rules affecting the steam electric industry recently: the Cooling Water Intake Structures (CWIS) rule for existing facilities (79 FR 48300), the CCR rule (80 FR 21302), and the CPP rule (FR publication forthcoming). EPA approached analyses associated with each rulemaking carefully. EPA also recognizes that the steam electric industry complying with three regulations cumulatively in a very short period of time may choose a different compliance path than assumed in the analyses. The cumulative effect introduces uncertainty on the compliance path, and thereby on the benefits and costs associated with these rules.

EPA expects that the operational changes prompted by the final ELGs will cause some plant owners to reduce their reliance on impoundments to manage coal combustion residuals. The CPP rule is likely to have similar effect on plant owners' reliance on impoundments. These changes will affect the future probability and/or magnitude of impoundment failures and the resulting accidental, and sometimes catastrophic, releases of coal combustion residuals. This rule takes the CPP rule into account in the baseline whereas the CCR rule did not, though it included the proposed CPP rule as a sensitivity analysis. Because the timing was such that the CCR rule did not include compliance with CPP in its main analysis, the benefits and costs for the ELGs of complying with the full set of rules may be higher than reported here, although EPA has done its best to incorporate the effect of all three rules in this analysis.

Benefits from the reduced risk of impoundment failures include avoided cleanup costs, environmental damage, and transaction costs. EPA's analysis of the monetary value of avoided impoundment failures is based on the identification of impoundments that would be affected by each of the regulatory options. EPA estimated benefits from avoided impoundment failures based on the probability of a release for each impoundment in a given year, the capacity of the impoundment, and the cost (including cleanup costs, natural resource damages (NRD) and transaction costs) per gallon of coal combustion residuals slurry spilled. Benefits are calculated as the difference between expected failure costs for a regulatory option and expected failure costs under baseline conditions, over the period of 2019 through 2042.

6.1 Methods and Data

This section describes the methodology and data used to determine the baseline and post-compliance probability of impoundment failures, assign costs to the releases, and estimate the total present and annualized values of benefits resulting from the final ELGs.

As described below, the ELG analysis follows an approach similar to that used in the final CCR rule analysis (U.S. EPA, 2014), but uses ELG-specific data and assumptions that reflect differences in the impoundment universe and failure probability. For example, the final ELG analysis considers a universe of 1,070 impoundments at 1,080 steam electric plants to which the ELGs apply (see Section 6.1.2), which is larger than the 735 impoundments analyzed for the CCR rule. Fifty-three of the impoundments in the Steam Electric universe are projected to close as a result of the CCR rule, leaving 1,017 impoundments in the ELG analysis baseline. The ELG analysis also uses assumptions that reflect implementation of the CCR rule in the ELG baseline. Thus, the risk of an impoundment failure applied to big impoundments subject to wall breaches (0.044 percent; see Section 6.1.1) reflects the residual risk remaining after implementation of the CCR rule, as compared to the higher historical rate of 0.09 percent used as baseline in the CCR rule analysis.

6.1.1 Baseline Failure Probability and Release Quantity

EPA estimated the future probability of coal combustion residuals releases from impoundments based on historical trends, accounting for the primary types of releases applicable to different types of impoundments. The approach builds on the methodology used by EPA Office of Resource Conservation and Recovery (ORCR) for the analysis of final regulations governing the disposal of CCR in impoundments (*i.e.*, "CCR rule"; U.S. EPA, 2014).

To determine the frequency of releases, EPA used data from a survey of impoundments conducted in support of the CCR rule (U.S. EPA, 2012d). The surveyed plants had a total of 656 CCR impoundments, and the survey obtained information from owners and operators about impoundment releases between 1999 and 2008. Two of the survey respondents also provided data for two additional releases that occurred in 1995 and 1998. In total, the survey provides data for 49 relevant historical releases[49] over a total of 6,565 impoundment-year observations.[50]

In response to the benefit analysis for the proposed ELGs, EPA received several comments noting that seepage events, which account for 13 of the 49 release events, are not likely to result in significant cleanup or other types of costs. EPA excluded these 13 seepage events from the historical release data used to determine the frequency of relevant releases. The remaining 36 releases are summarized in *Appendix J*.

EPA sorted the 36 releases into two categories based on the circumstances and cause of the release: *wall breaches* (4 releases), which are structural failures of external perimeter embankments, and *other releases* (32 releases). These other releases include overtopping (8 failures); miscellaneous causes (13 failures) such as sink hole, stack failure, pump failure, hydraulic dredging pipe failure, liner perforation, internal dike breach (not perimeter), seal failure, discharge structure disturbed during maintenance, and embankment slough; or unknown causes (11 releases).

EPA assumes, and the historical release data shows, that the potential for wall breaches exists only for large impoundments that meet certain structural integrity "factor of safety" design criteria specified in the CCR rule. These impoundments (labeled *big* for the purpose of the analysis) are those with:

- Height (impounding elevation) of five feet or more above the upstream toe, <u>and</u> storage volume of 20 acre-feet or more, <u>or</u>
- Height (impounding elevation) of 20 feet or more above the upstream toe.

Impoundments that do not meet either criterion (labeled *small*) are assumed not susceptible to failure by wall breach, but susceptible only to other types of releases. Based on these criteria, the ORCR survey (U.S. EPA, 2012d) includes 444 big impoundments and 212 small impoundments. EPA calculated the frequency of releases based on the 36 historic releases for each type of failure (wall breach vs. other) and type of impoundment (big vs. small).

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[49] This differs from the risk of failure estimated for the proposed ELG. For the proposed rule analysis, EPA had counted 42 CCR pond damage cases rather than the current count of 49 cases. EPA corrected the survey database for nine cases that had been entered as single incidents but were in fact separate incidents, leading to an interim total of 52 cases. Two of these 52 cases did not involve coal combustion residuals ponds (they involved a metal cleaning waste basin and a coal pile sump) and one case did not involve the release of impounded coal combustion residuals material (it involved an oil and grease exceedance due to servicing of a pump located near a coal combustion residuals pond).

[50] The survey responses provided 10 years of data for 656 impoundments, an additional 4 years of data for one impoundment, and an additional year of data for another impoundment, for a total of 6,565 observations (656 × 10 + 1×4 + 1×1).

The probability of a release is assumed to be uniform over time and across all impoundments within a category (big or small), irrespective of other impoundment characteristics such as age, amount of coal combustion residuals managed, etc. In practice, the probability of a release may depend on impoundment characteristics and could therefore change as a result of the final rule. However, EPA did not have sufficient data to model the probability as a function of impoundment characteristics.

The impoundment survey conducted by ORCR (see U.S. EPA, 2012d) provides data on the release volume and impoundment capacity for 17 of the 36 documented releases. For each type of release and impoundment category, EPA calculated a “capacity factor” that represents the ratio of gallons of coal combustion residuals released compared to the design capacity of the impoundment involved in the release.

Table 6-1 summarizes the historical probability of impoundment release and the capacity factor by release and impoundment type.

Table 6-1: Probabilities of CCR impoundment releases, based on analysis of 49 historical release events 1995–2008

Impoundment Type – Big ***(at least 5 feet high AND at least 20 acre-feet OR at least 20 feet high independent of volume)***		
Impoundments with observations for 10 years	444	
Additional observations (impoundment-years)	4	
Total number of observations	4,444	
Release Type	**Wall Breach**	**Other**
Number of releases	4	26
Probability of a release – number of releases per impoundment per year	0.09%	0.59%
Capacity factor – volume released as percent of capacity	27.42%	2.91%
Impoundment Type – Small ***(Does not fit "big" criteria)***		
Impoundments with observations for 10 years	212	
Additional observations (impoundment-years)	1	
Total number of observations	2,121	
Release Type	**Wall Breaches**	**Other**
Number of releases	Not applicable[a]	6
Probability of a release – number of releases per impoundment per year	Not applicable[a]	0.28%
Capacity factor – volume released as percent of capacity	Not applicable[a]	0.41%

a. Small impoundments only incurred "other" releases (no wall breaches).

Source: U.S. EPA Analysis, 2015

EPA adjusted the release probabilities shown in *Table 6-1* to account for implementation of the final CCR rule.[51] The rule establishes minimum national criteria for the storage of CCR in surface impoundments at coal-fired electric utility plants, regulating CCR as a non-hazardous waste. It requires standardized pollution control measures as well as monitoring and corrective actions in the event of a leak. Additionally, it subjects all impoundments to location restrictions, design and operating conditions, groundwater monitoring, closure requirements, and post-closure care. For more details on the CCR rule, see U.S. EPA (2014).

As detailed in U.S. EPA (2014), some plant owners may close their existing impoundments in response to the CCR rule, effectively eliminating the probability of a future release from these impoundments. For

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[51] The CCR rule is not expected to affect the capacity factors in the event of a release.

impoundments that remain operational, the CCR rule is expected to reduce the release rate through the implementation of structural integrity programs, including regular inspections and other safeguards. For these impoundments, EPA estimated that the CCR rule would reduce the probability of releases from big impoundments to 0.044 percent annually for wall breaches and to 0.16 percent for other releases (compared with 0.09 percent and 0.59 percent, respectively, in *Table 6-1*). For small impoundments, EPA expects that the CCR rule will reduce the probability of a release from 0.28 percent (*Table 6-1*) to 0.07 percent. See U.S. EPA (2014) for more detail on these release probability assumptions.

Table 6-2 summarizes the release probability and capacity factor assumptions used for big and small impoundments in this analysis, taking the effects of the CCR rule into account.

Table 6-2: Release Probability and Capacity Factor Assumptions for the ELGs

Type	Annual Probability of Release		Capacity Factor	
	Wall Breach	Other Release	Wall Breach	Other Release
Big	0.044%	0.16%	27.42%	2.91%
Small	NA	0.07%	NA	0.41%

Source: U.S. EPA Analysis, 2015

6.1.2 Effects of the ELGs

The 1,080 steam electric power plants subject to the Steam Electric ELGs have a total of 1,070 impoundments. Following implementation of the CCR rule, EPA expects 1,017 of these impoundments to continue operation as of 2023. As discussed in *Section 1.3*, EPA included the effects of the CPP rule in the baseline for the ELG analysis. EPA projects that the CPP rule will result in some generating unit ceasing operation (retiring) or converting, which will also affect impoundments that receive wastestream from the units. Due to the uncertainty in plant owners' decision to continue to operate impoundments at plants where some but not all generating units are converted or retire, EPA estimated the impacts of the CPP in two ways:

- Low bound estimate: EPA adjusted impoundment capacity only for those plants where *all* units that send wastewater streams to an impoundment retire as a result of the CPP rule.
- High bound estimate: EPA adjusted impoundment capacity considering the share of the generating capacity of units that retire as a result of the CPP rule.

This CPP-adjusted universe of impoundments (883 to 925 impoundments) represents the baseline for the ELG analysis, i.e., EPA evaluates the incremental impacts of the ELG on those impoundments EPA determined would handle coal combustion residuals wastestreams by the time the plant would comply with the ELGs after accounting for both the CCR and CPP rules.

EPA categorized these impoundments as big or small following the criteria outlined in *Section 6.1.1*. EPA used the Steam Electric Industry survey (U.S. EPA, 2010c) as the primary source of impoundment size data, supplemented by information collected in the CCR survey (see U.S. EPA 2012d) for impoundments that are common to both data sets.[52] *Table 6-3* summarizes the results.

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[52] To categorize each of the impoundments as big or small, EPA imputed impoundment height based on the volume, difference in elevation, and the reported maximum berm height from U.S. EPA (2010b). Together with this height data, EPA used the reported capacity to categorize impoundments that are clearly either big or small. EPA used ORCR impoundment data (from U.S. EPA 2010c) to categorize an additional 69 impoundments where there was clear overlap between the two impoundment data sets. EPA categorized an additional 187 impoundments as big based on at least one height indicator being over 20 feet or at least one height indicator

Table 6-3: Steam Electric Impoundments by Size in ELG Baseline

Type	Number of Impoundments			Impoundment Capacity		
	Count		Percent of Total	Total (million gallons)		Percent of Total
	Low Bound	High Bound		Low Bound	High Bound	
Big	632	668	72%	687,758	713,317	95%
Small	251	257	28%	34,336	34,348	5%
Total	**883**	**925**	**100%**	**722,094**	**747,665**	**100%**

Source: U.S. EPA Analysis, 2015

For each of these impoundments, EPA estimated the expected number of magnitude of releases for each year between 2019 and 2042, and estimated the expected costs associated with the releases. EPA did this calculation for the baseline and under each of the five regulatory options.

Specifically, EPA used the probability of release established based on the historic data and revised to account for implementation of the CCR rule (*Table 6-2*) to estimate the expected number of releases from each of the steam electric power plant impoundments in the baseline. EPA used the applicable capacity factor to estimate the volume involved in a release from each impoundment. For example, EPA assumes that an “other” release from a big impoundment involves a volume of coal combustion residuals equal to 2.91 percent of the impoundment’s capacity. *Figure 6-1* illustrates assumptions used for the baseline scenario.

The Steam Electric ELG is anticipated to change how plant owners or operator handle their coal combustion residuals, potentially reducing the quantity of FGD solids or ash managed using impoundments. This lower coal combustion residuals volume is in turn expected to reduce the amount of coal combustion residuals accumulating in the impoundments in any given year. For this analysis, EPA assumed that the amount of coal combustion residuals released in the event of a wall breach or other release is reduced in proportion to the reduction in the amount of coal combustion residuals handled by the impoundment. Thus, for each scenario, EPA assumed that an impoundment has the same expected number of releases post-compliance, but calculated the volume released by multiplying the capacity factor by an adjusted volume that reflects the reduction in the amount of coal combustion residuals handled wet (see U.S. EPA, 2015g; DCN SE05831(CBI version / DCN SE05832 (non-CBI version) for the calculations). EPA assumed that the reduction in volume occurs in the same year as the technology implementation year assumed in other parts of the analysis (see *Section 1.5.3*).

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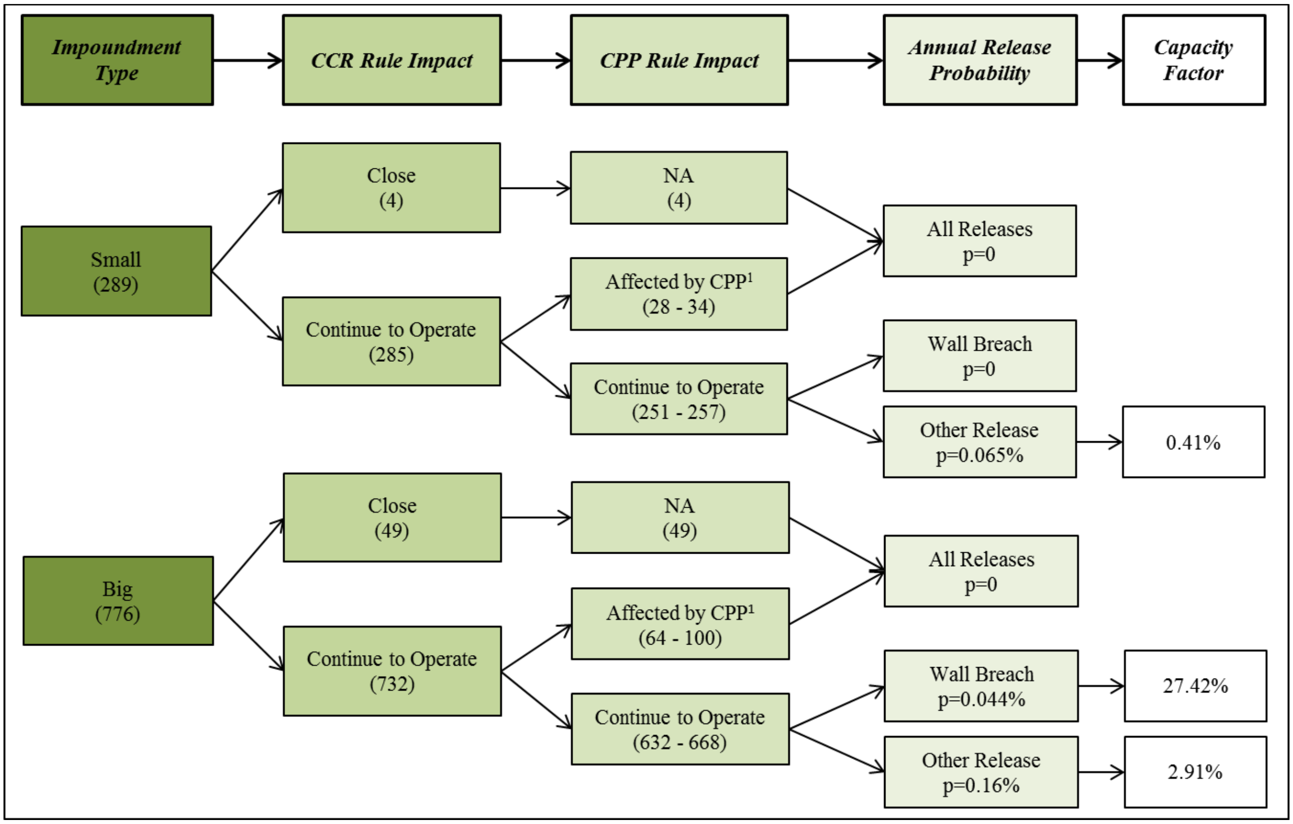
being over 5 feet together with capacity over 20 acre-feet. For impoundments for which no height data was provided, EPA categorized impoundments based on capacity only.

Figure 6-1: Baseline Release Probability and Capacity Factor Assumptions



[1] Changes in the risk of impoundment failure in impoundments affected by the CPP rule are not attributable to the ELGs and do not generate benefits attributable to the ELGs in this analysis.

6.1.3 Costs of a Release

The following sections discuss three categories of costs associated with impoundment releases: cleanup, NRD, and transaction costs. All dollar values are presented in year 2013 dollars.[53]

6.1.3.1 Cleanup Costs

EPA estimated per-gallon cleanup costs based on five historical impoundment failures. The average unit cost associated with these historical incidents is $1.35 per gallon released (see *Table 6-4*). Details on the five incidents are provided below and reflect additional research EPA conducted since the proposed ELG analysis.

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[53] As needed, costs were updated to 2013 dollars using the Construction Cost Index from the Engineering News Report (unless otherwise indicated).

Table 6-4: Documented Cleanup Costs from Impoundment Releases

Incident	Volume Spilled (million gallons)	Cleanup Cost (millions; 2013$)	Unit Cleanup Cost (2013$)
Oak Creek	5	$13	$2.83
TVA Widows Creek	6	$10	$1.64
Martins Creek	100	$62	$0.62
Massey	230	$89	$0.39
TVA Kingston	1,100	$1,379	$1.25
Average	**288**	**$311**	**$1.35**

The Oak Creek release occurred in October 2011 when a bluff collapsed near an ongoing construction project at the Wisconsin Energy Oak Creek power plant, releasing 22,720 cubic yards (or 4.6 million gallons) of coal ash into Lake Michigan. The collapse also carried "debris from the construction worksite, including vehicles, heavy machinery, a filter press, a frac tank and four miscellaneous conex boxes filled with unknown amounts of miscellaneous equipment, down the bluff and into Lake Michigan." (Wisconsin Department of Justice (DOJ), 2013). Wisconsin Energy's immediate response to the spill included the placement of 1,500 feet of containment berms and booms and a geotechnical analysis of the stability of the bluff (Wisconsin DOJ, 2013; Jones and Behm, 2011). Additional response actions included excavation and removal of the material that had been spilled, with cleanup being complete by the end of November 2011 (Wisconsin DOJ, 2013). According to the U.S. EPA On-Scene Coordinator (U.S. EPA OSC, 2012), Wisconsin Energy reported spending $12.1 million on cleanup and restoration. After updating to 2013$ (for a total of $13 million), unit costs are $2.83 per gallon spilled.

The Tennessee Valley Authority (TVA) Widows Creek spill involved the release of 6.1 million gallons of gypsum, water, and fly ash. Updated to 2013$, cleanup costs for dredging of the creek and other activities were approximately $10 million (TVA, 2009), or $1.64 per gallon spilled.

The Martins Creek release involved the discharge of 100 million gallons of slurry over the course of 3 days, resulting from the failure of a wooden stop log. In its 2006 annual report (PPL Corporation, 2006), PPL Corporation estimated that the costs of the remediation effort were $48 million. After updating the revised costs to 2013$ (for a total cost of $62 million), the unit cost of this spill is $0.62 per gallon spilled.

The Massey Coal slurry spill involved the collapse of a 2,000 acre-foot (651.7 million gallon) surface impoundment on top of an idled underground mine. The Massey Energy 2002 annual financial report (10-K; Massey Energy, 2002) states that the release involved 230 million gallons and that Massey incurred a total of $58.3 million of cleanup costs in connection with the spill. Updated to 2013$ (for a total cost of $89 million), the unit cost for this spill is $0.39 per gallon spilled.

The TVA Kingston release involved approximately 1.1 billion gallons of slurry being released from an ash pond onto 300 acres, primarily the Watts Bar Reservoir and shoreline property. The spill also damaged three homes, interrupted utility services, and blocked a local road (TVA, 2009). Cleanup activities included ash dredging and processing, ash disposition, infrastructure repair, dredge cell repair, dike reinforcement, construction of temporary ash storage basins, and others. Updated to 2013$, the cleanup costs were approximately $1.38 billion (TVA, 2010; 2011), or $1.25 per gallon spilled.

In early February 2014, a coal ash release occurred at the Dan River power plant operated by Duke Energy in North Carolina. The release of 24 to 27 million gallons of ash and ash pond water was caused by a break in a 48-inch stormwater pipe beneath the ash basin (Duke Energy, 2014). Cleanup involved the removal of 2,500 tons of ash and contaminated sediment that settled against a dam, and an additional 500 tons that settled in other parts of the river and municipal water treatment settling tanks (Associated Press, 2014).

Duke Energy has stated that company investors and insurers will pay for the cleanup rather than ratepayers (Duke Energy, 2014). Duke Energy's second quarterly financial report in 2014 reports that the company spent approximately $20 million in repairs and remediation related to the spill through June 2014, and completed cleanup in July. Additionally, according to a plea agreement signed by Duke Energy subsidiaries on May 14, 2015, Duke Energy agreed to spend $34 million for environmental damages, including a $24 million payment to the National Fish and Wildlife Foundation to benefit riparian areas of North Carolina and Virginia, plus $10 million in wetland mitigation bank credits. Total cleanup costs, transaction costs, and NRD were not available at the time that EPA conducted this analysis, however, and this incident was therefore not included in the cleanup costs shown in *Table 6-4*, nor used in this analysis.

6.1.3.2 Natural Resource Damages

Israel (2006) provides a detailed state-by-state summary of NRD programs, including some prominent cases (arising from oil spills, chemical spills, and other incidents) in each state. Israel (2013) provides an updated version of the accounting with additional cases identified since the 2006 study. *Appendix J* lists the 137 NRD cases from Israel (2006; 2013) that provide quantitative estimates of NRD restoration and compensation costs.[54]

Releases resulting from impoundment failures may affect resources similar to those that were affected by some of the NRD cases identified in Israel (2006; 2013) and therefore would be expected to have similar NRD costs. Of the 137 NRD settlements identified in Israel (2006; 2013), EPA identified 65 cases that are relevant to this analysis based on the resources affected and the general circumstances of the releases. In particular, EPA excluded as potentially less relevant settlements for NRD, which, based on the description provided in Israel, involved damage to groundwater only or to ocean/coastal resources, or resulted from legacy pollution associated with Superfund sites.

Table 6-5 shows summary statistics for the 65 NRD settlements EPA retained as relevant to this analysis, compared to the summary statistics for the cleanup costs in *Table 6-4*. As shown in the table, the mean NRD settlement is approximately $13.7 million, or 4 percent of the mean total cleanup cost.

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[54] NRD does not include cleanup costs (or legal and transaction costs, if reported) but includes only the resource restoration and compensation values. For example, in one case, Israel (2006) reported that "In total, the State's claim was $764 million, $342 million of which was restoration cost damages, $410 million of which was compensable value damages, and $12 million of which was assessment and legal costs." For this case, EPA used the sum of $342 million and $410 million as NRD (*i.e.*, excluded assessment and legal costs). EPA used values for individual cases discussed in the study, focusing exclusively on NRD and excluding or subtracting assessment costs when those costs were reported separately. EPA also excluded NRD values that represent the aggregate of several cases when it was not possible to discern NRD for individual cases.

Table 6-5: NRD Settlements Summary Statistics

	Natural Resource Damages (2013$)[a]	Cleanup Costs (2013$)[b]	NRD as a Percent of Cleanup Costs
Minimum	$44,000	$10,000,000	0%
Median	$1,965,000	$62,000,000	3%
Mean	$13,723,000	$311,000,000	4%
Maximum	$439,545,000	$1,379,000,000	32%

a. Based on Israel (2006; 2013); updated using changes in the GDP. If a year is not provided for a case, EPA updated the value based on the year of the study that identified the case (*i.e.*, 2006 or 2013).

b. Based on cleanup costs in Table 6-4.

To estimate expected NRD costs for future impoundment releases, EPA assumed that the NRD varies depending on the magnitude of the release in proportion to cleanup costs. To derive a per-gallon estimate of the expected NRD value for future releases, EPA divided the mean NRD settlement of $13.7 million by the mean cleanup cost ($311 million). This calculation yields an NRD estimate of 4 percent of cleanup costs, or $0.05 per gallon spilled (4 percent of $1.35 /gallon).

Note that this estimate provides an approximate value for NRD resulting from impoundment failures as a function of the volume of coal combustion residuals released, and is appropriate for analyses that look at NRD over a range of locations and circumstances. EPA expects that actual damages from any given release would be highly location- and release-specific.

6.1.3.3 Transaction Costs

For this analysis, transaction costs include the costs associated with negotiating NRD, determining responsibility among potentially responsible parties, and litigating details regarding settlements and remediation.[55] EPA estimated transaction costs based on data showing transaction costs as a share of total cleanup costs at Superfund sites and the share of spending that represents total transaction costs. *Table 6-6* shows the data sources.

Table 6-6: Studies Summarizing Transaction Costs as a Share of Superfund Spending (for potentially responsible parties)

Acton (1995)	27%
Acton and Dixon (1992)	17%
Dixon, et al. (1993)	32%
Steinhardt et al. (1994)	33%
Average	**27%**
Multiplier (transaction costs as a share of cleanup cost)[a]	**37%**

a. Multiplier is calculated as Average/(1 - Average)

These data indicate that, on average, transaction costs represent 27 percent of total costs. As the purpose is to estimate unit costs per gallon spilled, transactions costs represent 37 percent of the subset of costs that are

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[55] These activities involve services, whether performed by the complying entity or other parties, that EPA expects would be required in the absence of this final rule in the event of an impoundment failure. Accordingly, it is appropriate to account for the avoided resource cost of these services as social benefits in the benefit-cost analysis. Note that the transaction costs do not include fines, cleanup costs, damages, or other costs that constitute transfers or are already accounted for in the other categories analyzed separately.

cleanup costs, calculated as 0.27/(1-0.27). Therefore, the estimated transaction costs per gallon of coal combustion residuals slurry spilled are $0.50 (37 percent of $1.35/gallon).

6.1.3.4 Total Release Costs

Table 6-7 summarizes unit costs for cleanup costs, NRD, and transaction costs. Total impoundment release costs are $1.90 per gallon spilled.[56]

Table 6-7: Unit Costs for Impoundment Releases (2013$)

Cost Component	Unit Cost ($/gallon spilled)
Cleanup costs	$1.35
NRD	$0.05
Transaction costs	$0.50
Total costs	**$1.90**

6.2 Results

The final ELGs will provide benefits by reducing the impact of releases from impoundments that are expected to see reduced utilization as a result of the final rule, but would continue to operate in the absence of the final rule. For each of the impoundments included in the analysis, EPA calculated the difference between the annualized costs from future expected failures under the baseline and each analyzed regulatory option. The calculation involves the following steps:

- Multiplying the release rate for a given impoundment and year by the capacity factor, impoundment volume (adjusted if needed to reflect the effects of the ELG), and total unit costs for the release (including cleanup, NRD, and transaction costs);
- For each regulatory scenario, subtracting the costs of expected releases from the cost of expected releases under the baseline; and
- Discounting for future years, aggregating across the analysis time horizon (2019 to 2042), and annualizing over a 24-year period using rates of 3 percent and 7 percent.

Table 6-8 shows the total number of impoundment failures estimated over the period of 2019-2042 in the baseline and under each of the five regulatory options. Expected failures are reported as a range to reflect the range of the anticipated effects of the CPP rule discussed in Section 6.1.2. These values reflect the number and types of impoundments (big and small) and the associated failure probability for each type of failure (wall breach and other). *Table 6-9* shows the estimated volume of coal combustion residuals released annually in these expected failures, after full compliance by all steam electric power generating plants. Estimates of the coal combustion residuals volume released reflect the size of the impoundments involved in the expected failures and the capacity factor for each type of failure.

The number of failures estimated in the ELG baseline (approximately 8 wall breaches and 33 other failures over 24 years) is consistent with the post-compliance failures estimated in the final CCR rule analysis (15 wall breaches and 91 other releases over 100 years; see U.S. EPA 2014), given differences in the impoundment universe noted in the introduction to this Chapter. Similarly, the number of avoided failures estimated to result from implementation of the final ELGs (Option D), which is approximately 2 wall

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[56] In the economic analysis of the proposed rule, EPA capped release costs for any single incident at $1.3 billion based on the total estimated cleanup costs of the TVA Kingston spill. However, EPA removed this cap for the final rule analysis, since future incidents could feasibly exceed the damages associated with Kingston.

breaches and 7 other releases over 24 years, seems consistent with the number of avoided failures estimated for the final CCR rule (32 wall breaches and 429 other releases over 100 years; see U.S. EPA 2014), given the differences in the universe of impoundments and in assumptions regarding the failure rate for the ELG analysis.

Table 6-8: Total Expected Number of Releases in 2019 through 2042, by Failure Type

Regulatory Option	Expected Number of Failures		Reduction in Expected Number of Failures	
	Wall Breaches	Other Releases	Wall Breaches	Other Releases
Low Bound Estimate of CPP Effects				
Baseline	7.7	32.6	0.0	0.0
Option A	7.3	30.8	0.4	1.7
Option B	7.3	30.8	0.4	1.7
Option C	6.7	28.1	1.0	4.5
Option D	6.1	25.7	1.6	6.9
Option E	6.1	25.7	1.6	6.9
High Bound Estimate of CPP Effects				
Baseline	7.7	32.6	0.0	0.0
Option A	7.2	30.4	0.5	2.1
Option B	7.2	30.4	0.5	2.1
Option C	6.5	27.4	1.2	5.2
Option D	5.8	24.4	1.9	8.1
Option E	5.8	24.4	1.9	8.1

Source: U.S. EPA Analysis, 2015

Table 6-9: Expected Total Coal Combustion Residuals Volume Released Annually, by Failure Type (Million Gallons)

Regulatory Option	Estimated CCR Volume Released			Estimated Reduction in CCR Volume Released[a]		
	Wall Breaches	Other Releases	All Releases	Wall Breaches	Other Releases	All Releases
Low Bound Estimate of CPP Effects						
Baseline	125	48	173	0	0	0
Option A	115	45	160	9	4	13
Option B	115	45	160	9	4	13
Option C	88	34	122	37	14	51
Option D	82	32	114	42	16	59
Option E	82	32	114	42	16	59
High Bound Estimate of CPP Effects						
Baseline	125	48	173	0	0	0
Option A	114	44	158	10	4 - 4	14
Option B	114	44	158	10	4 - 4	14
Option C	86	33	119	39	14 - 15	54
Option D	79	31	110	45	16 - 18	63
Option E	79	31	110	45	16 - 18	63

Source: U.S. EPA Analysis, 2015

a. The values reflect reductions in the volume of coal combustion residuals released in expected failures for years 2023-2042, after compliance by all steam electric power generating plants. Reductions in years 2019-2022 are less than reported in this table due to the assumed distribution of permit renewals and control technologies implementation over the period of 2019 through 2023.

Table 6-10 shows the total benefits of avoided impoundment failures, calculated as the sum of the avoided release costs across all impoundments expected to be affected by the final rule under each analyzed regulatory option. The range of benefits reflects the range of the anticipated effects of the CPP rule discussed in Section 6.1.2. For each option, avoided wall breaches account for 72 percent of benefits, while other releases account for the remaining 28 percent.

Table 6-10: Estimated Annualized Benefits of Avoided Impoundment Failures by Release Type (Millions; 2013$)[a]

Discount Rate	Regulatory Option	Wall Breaches		Other Releases		All Releases	
		Low Bound	High Bound	Low Bound	High Bound	Low Bound	High Bound
3%	Option A	$14.5	$16.5	$5.6	$6.4	$20.1	$22.9
	Option B	$14.5	$16.5	$5.6	$6.4	$20.1	$22.9
	Option C	$59.3	$62.7	$22.9	$24.2	$82.2	$86.9
	Option D	$68.8	$74.1	$26.7	$28.8	$95.6	$102.9
	Option E	$68.8	$74.1	$26.7	$28.8	$95.6	$102.9
7%	Option A	$11.6	$13.3	$4.5	$5.1	$16.1	$18.4
	Option B	$11.6	$13.3	$4.5	$5.1	$16.1	$18.4
	Option C	$47.9	$50.7	$18.5	$19.6	$66.4	$70.3
	Option D	$55.9	$60.3	$21.7	$23.4	$77.7	$83.7
	Option E	$55.9	$60.3	$21.7	$23.4	$77.7	$83.7

Source: U.S. EPA Analysis, 2015

a. Baseline value of total failure costs minus option value of total failure costs.

6.3 Implications of Revised Steam Electric Plant Loading Estimates

As described in *Section 1.4.3*, EPA revised its estimates of pollutant loadings in steam electric power plant discharges after completing the benefit analyses. Estimated benefits from avoided impoundment failures do not depend on pollutant loadings and therefore the monetized benefit estimates provided in this Chapter are unaffected by revisions to steam electric plant loading estimates.

6.4 Limitations and Uncertainties

Table 6-11 summarizes the limitations and uncertainties in the analysis of benefits associated with reduced impoundment failures arising from the final rule. The methodologies used in this analysis involve several simplifications and sources of limitations and uncertainties, as described below. These uncertainties add to the limitations and uncertainties inherited from the EA analysis and data (see U.S. EPA, 2015a). Whether these limitations and uncertainties, taken together, are likely to result in an understatement or overstatement of the estimated benefits is not known.

Table 6-11: Limitations and Uncertainties in Analysis of Avoided Risk of Impoundment Failure Benefits

Uncertainty/Assumption	Effect on Benefits Estimate	Notes
The analysis assumes that, in the absence of the final rule, all impoundments would continue to operate in the baseline during the entire period of analysis.	Overestimate	Plant owners may close existing impoundments or make other changes to their operations that would reduce the baseline probability of failure. Not accounting for these baseline conditions may overstate the benefits of the final rule.
The analysis accounts for projected closures of steam electric plant impoundments due to the CCR rule as of 2023 (53 impoundments). The analysis does not account for additional projected closures in 2024-2042 due to the CCR rule.	Overestimate	To the extent that additional impoundments are projected to close due to the CCR rule after implementation of the ELGs and EPA estimated benefits for these closures as part of the CCR rule analysis, EPA may be overstating the *incremental* benefits of the ELGs. The magnitude of overstatement is unknown but is expected to be small given the relatively few closures projected overall in the CCR rule analysis (98 impoundments close by 2114 out of the total of 735 impoundments analyzed; see U.S. EPA 2014), the timing of these projected future closures, and the effects of discounting on annualized benefit estimates. Furthermore, EPA's adjustment to the ELG benefit analysis to reflect impoundment closures due to the CCR rule is consistent with the adjustment to ELG compliance costs.
EPA estimated expected future impoundment releases from big and small impoundments based on uniform release rates for wall breaches and other releases. In practice, the probability of failure may depend on impoundment characteristics and management practices.	Uncertain	Using a uniform failure rate may understate benefits of the final rule. Conversely, the historical failure rate may overstate projected failures under baseline conditions by not reflecting the effects of any recent changes in impoundment management practices (*e.g.*, revised inspection and monitoring programs).
The analysis uses a uniform cost of $1.90 per gallon spilled, including cleanup costs, natural resource damages, and transaction costs.	Uncertain	There is significant uncertainty involved in estimating the costs of unknown future release incidents, and these estimates are based on a small and highly variable sample of historic releases. The costs of future releases may be substantially higher or lower than the cost estimates applied in this analysis, depending on site-specific factors, including the ecosystems, infrastructure, and other resources damaged by the release.

7 Air-Related Benefits

The final rule is expected to affect air pollution through three main mechanisms: 1) additional auxiliary electricity use by steam electric power plants to operate wastewater treatment, ash handling, and other systems needed to comply with the new effluent limits and standards; 2) additional transportation-related emissions due to the increased trucking of CCR 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 for the ELGs. The different profile of generation can result in lower or higher air pollutant emissions due to differences in emission factors. Thus, small reductions in coal-based electricity generation as a result of the ELGs are compensated by increases in generation using other fuels or energy sources – biomass, landfill gas, natural gas, nuclear power, oil, and wind power. For example, as detailed in Section 10.6 of the RIA (U.S. EPA, 2015c), IPM projects a 0.3 percent decline in electricity generation from coal (3,276 GWh), as a result of the final ELGs (Option D); this decline is offset by a 0.1 percent increase in natural gas generation (1,964 GWh) and additional increases in electricity generation from waste coal, wind, and biomass. The changes in air emissions reflect the differences in emissions factors for these other fuels or sources of energy, as compared to coal.

In this analysis, EPA estimated the human health and other benefits resulting from net changes in emissions of three pollutants: NO_X, SO_2, and CO_2.

NO_x and SO_x (which include SO_2 emissions quantified in this analysis) are known precursors to fine particles ($PM_{2.5}$) air pollution, a criteria air pollutant that has been associated with a variety of adverse health effects – most notably, premature mortality.[57] In addition, in the presence of sunlight, NO_X and VOCs can undergo a chemical reaction in the atmosphere to form ozone. Depending on localized concentrations of volatile organic compounds (VOCs), reducing NO_X emissions would also reduce human exposure to ozone and the incidence of ozone-related health effects. Reducing emissions of SO_2 and NOx would also reduce ambient exposure to SO_2 and NO_2, respectively. For the purpose of this analysis, EPA quantified only those benefits from associated reductions $PM_{2.5}$.[58]

CO_2 is an important greenhouse gas that is linked to climate change effects, including: an increase in temperature; sea level rise; changes in weather patterns toward an intensified water cycle with stronger floods and droughts; and stress on ecosystems, especially in the Arctic, mountain and tropical areas, resulting in the shift of species habitat range. The expected economic losses from climate change include reduced agricultural yields, human health risks, property damages from increased flood frequencies, the loss of ecosystem services, etc. Increased CO_2 levels also affect biological systems independent of climate change. For example, oceans become markedly more acidic, endangering coral reefs and potentially harming fisheries and other marine life (Intergovernmental Panel on Climate Change (IPCC), 2014).

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[57] Sulfur oxides (SOx) include sulfur monoxide (SO), sulfur dioxide (SO_2), sulfur trioxide (SO_3) and other sulfur oxides. In this analysis, EPA analyzed changes in emissions of SO_2 only.

[58] The Integrated Science Assessment for Particulate Matter (PM ISA) (U.S. EPA, 2009b) identified the human health effects associated with ambient PM2.5 exposure, which include premature morality and a variety of morbidity effects associated with acute and chronic exposures. Similarly, the Integrated Science Assessment for Ozone and Related Photochemical Oxidants (Ozone ISA) (U.S. EPA, 2013c) identified the human health effects associated with ambient ozone exposure, which include premature morality and a variety of morbidity effects associated with acute and chronic exposures.

7.1 Data and Methodology

7.1.1 Changes in Air Emissions

As discussed in the *RIA (Chapter 5: Electricity Market Analyses)*, EPA used the Integrated Planning Model (IPM) to estimate the electricity market-level effects of two of the five regulatory options (Options B and D; see *Chapter 5* in *RIA* (U.S. EPA, 2015c)). IPM outputs include NO_x, SO_2, and CO_2 emissions to air from electricity generating units (EGU). Comparing these emissions to those projected for the base case provides an assessment of the changes in air emissions resulting from changes in the profile of electricity generation under the final rule. EPA used four run years, 2020, 2025, 2030, and 2040, to represent the periods of 2019-2022, 2023-2027, 2028-2033, and 2034-2042, respectively (for a more detailed discussion of the IPM analysis years, refer to *Chapter 5* in *RIA*).

EPA developed separate estimates of air emissions associated with increases in electricity generation to power wastewater treatment systems by multiplying plant-specific additional electricity consumption estimated as part of the engineering analysis by plant- or North American Electric Reliability Corporation (NERC)-specific emission factors obtained from IPM for each analysis year. EPA estimated air emissions associated with increased trucking by multiplying the number of miles by average emission factors. Details of these two analyses are provided in the *TDD*.

Table 7-1 through *Table 7-3* summarize the estimated changes in emissions for the three mechanisms, the three pollutants, and the two regulatory options covered in this particular analysis. As shown in the tables, EPA estimates that changes in auxiliary service (*Table 7-1*) and transportation (*Table 7-2*) would result in an increase in emissions (positive values), while changes in the profile of electricity generation (*Table 7-3*) would reduce CO_2, SO_2 and NOx emissions (negative values). *Table 7-4* presents the net emissions changes across the three mechanisms.

The largest effect on projected air emissions is due to the change in the emissions profile of electricity generation at the market level. As presented in the *RIA* (*Section 10.6: Executive Order 13211: Actions Concerning Regulations That Significantly Affect Energy Supply, Distribution, or Use*), IPM projects small reductions in electricity generation coming from coal as a result of the ELGs (less than 0.1 percent for Option B; 0.3 percent for Option D), which is compensated with increases in generation using other fuels or energy sources – biomass, landfill gas, natural gas, nuclear power, and wind power. The changes in air emissions reflect the differences in emissions factors for these other fuels, as compared to coal.

Table 7-1: Estimated Changes in Electricity Consumption and Air Pollutant Emissions due to Increase in Auxiliary Service at Steam Electric Power Plants, Relative to Baseline

Regulatory Option	Year	Electricity Consumption (MWh)	CO_2 (Metric Tonnes/Year)	NOx (Tons/Year)	SO_2 (Tons/Year)
Option B	2015-2018	0.0	0.0	0.0	0.0
	2019	30,859.8	27,409.7	13.9	35.9
	2020	41,529.5	36,972.7	20.5	45.4
	2021	72,651.5	63,257.8	35.4	69.4
	2022	86,488.4	75,759.4	45.2	75.6
	2023-2042	102,168.7	89,632.5	59.6	86.7

Table 7-1: Estimated Changes in Electricity Consumption and Air Pollutant Emissions due to Increase in Auxiliary Service at Steam Electric Power Plants, Relative to Baseline

Regulatory Option	Year	Electricity Consumption (MWh)	CO_2 (Metric Tonnes/Year)	NOx (Tons/Year)	SO_2 (Tons/Year)
Option D	2015-2018	0.0	0.0	0.0	0.0
	2019	60,680.1	55,222.0	35.3	59.2
	2020	94,172.8	83,855.3	64.7	84.4
	2021	152,706.0	134,385.6	95.7	132.0
	2022	192,404.2	169,583.1	128.3	162.3
	2023-2042	237,367.0	208,881.9	164.9	195.8

Source: U.S. EPA Analysis, 2015; see TDD for details.

Table 7-2: Estimated Changes in Annual Air Pollutant Emissions due to Increased Trucking at Steam Electric Power Plants, Relative to Baseline

Option	Year	CO_2 (Metric Tonnes/Year)	NOx (Tons/Year)	SO_2 (Tons/Year)
Option B	2015-2018	0.0	0.0	0.0
	2019	550.9	0.2	0.0
	2020	691.5	0.3	0.0
	2021	865.3	0.4	0.0
	2022	925.2	0.4	0.0
	2023-2042	982.5	0.4	0.0
Option D	2015-2018	0.0	0.0	0.0
	2019	2,111.5	0.9	0.0
	2020	2,480.3	1.1	0.0
	2021	3,244.6	1.4	0.0
	2022	3,641.2	1.6	0.0
	2023-2042	3,767.8	1.6	0.0

Source: U.S. EPA Analysis, 2015; see TDD for details.

Table 7-3: Estimated Changes in Annual Air Pollutant Emissions due to Changes in Electricity Generation Profile, Relative to Baseline

Regulatory Option	Year	CO_2 (Metric Tonnes/Year)	NOx (Tons/Year)	SO_2 (Tons/Year)
Option B	2015-2018	0.0	0.0	0.0
	2019-2022	-2,057,293.5	-3,534.5	-4,620.6
	2023-2027	-1,437,164.1	-3,323.9	-527.5
	2028-2033	-246,295.3	-1,361.2	1,315.7
	2034-2042	-1,186,462.9	-1,500.2	-1,608.4
Option D	2015-2018	0.0	0.0	0.0
	2019-2022	-4,869,524.3	-14,614.0	-5,662.8
	2023-2027	-2,555,361.0	-11,615.0	2,238.4
	2028-2033	-2,089,591.4	-8,826.0	-984.2
	2034-2042	-3,193,009.0	-10,638.8	-4,243.9

Source: U.S. EPA Analysis, 2015; see TDD for details.

Table 7-4: Estimated Net Changes in Air Pollutant Emissions due to Increase in Auxiliary Service at Steam Electric Power Plants, Increased Trucking at Steam Electric Power Plants, and Changes in Electricity Generation Profile, Relative to Baseline

Regulatory Option	Year	CO_2 (Metric Tonnes/Year)	NOx (Tons/Year)	SO_2 (Tons/Year)
Option B	2015-2018	0.0	0.0	0.0
	2019	-2,029,332.9	-3,520.3	-4,584.6
	2020	-2,019,629.3	-3,513.7	-4,575.1
	2021	-1,993,170.4	-3,498.7	-4,551.2
	2022	-1,980,609.0	-3,488.9	-4,545.0
	2023-2027	-1,346,549.1	-3,263.9	-440.8
	2028-2033	-155,680.3	-1,301.2	1,402.5
	2034-2042	-1,095,847.9	-1,440.2	-1,521.7
Option D	2015-2018	0.0	0.0	0.0
	2019	-4,812,190.8	-14,577.7	-5,603.6
	2020	-4,783,188.7	-14,548.2	-5,578.4
	2021	-4,731,894.1	-14,516.9	-5,530.8
	2022	-4,696,300.0	-14,484.1	-5,500.5
	2023-2027	-2,342,711.3	-11,448.4	2,434.3
	2028-2033	-1,876,941.7	-8,659.4	-788.3
	2034-2042	-2,980,359.3	-10,472.3	-4,048.0

Source: U.S. EPA Analysis, 2015

7.1.2 NO_x and SO_2

Detailed human health benefits analyses for air regulations typically involve the use of a sophisticated air quality model, such as the Community Multiscale Air Quality (CMAQ) Model, and BenMAP, EPA's principal air pollution benefits analysis modeling tool. The air quality model estimates the changes in concentrations of criteria air pollutants in each cell of a grid resulting from changes in emissions to air (*e.g.*, of NO_x and SO_2) under various policy scenarios. These criteria air pollutant changes are then input to BenMAP, which estimates the resulting changes in incidence in the exposed population of the adverse health effects associated with the pollutants and the corresonding monetized benefits (see (Abt Associates, 2012) for additional description of BenMAP). This detailed approach for human health benefits analysis of air regulations tends to be time- and resource-intensive.

Recognizing that a less resource- and time-intensive approach is sometimes desirable, EPA relied on the best available methods of benefits transfer, which is the science and art of adapting primary research from similar contexts to estimate benefits for the environmental quality change under analysis. EPA's Air Office developed estimates of national monetized benefits per ton of emissions avoided for use in estimating benefits without the need to conduct detailed air quality and human health benefits modeling. The benefit per ton values repsent the total monetized human health co-benefits, premature mortaility and premature morbidity, from the reduction in one ton of $PM_{2.5}$ (or $PM_{2.5}$ precursor such as NO_X or SO_2). Because the benefits per ton of emissions depend on both the type of emissions (*e.g.*, NO_x vs. SO_2) and the geographic distribution (relative to population centers) of the emitting sources, EPA developed benefits per ton estimates for specific combinations of emission source categories and $PM_{2.5}$ precursors. EPA used this approach, for example, in its assessment of the benefits of PM and SO_2 reductions for the Industrial Boiler and Process Heaters National Emissions Standards for Hazardous Air Pollutants (NESHAP) rule (U.S. EPA 2004a) and its analysis of the Mobile Source Area Toxics Rule (U.S. EPA 2004b) (See also Fann et al., 2012; Fann et al., 2009; Levy et al., 2009; and Muller and Mendelsohn, 2009).

EPA's calculation of the benefits per ton values involved three principal steps, as described by Fann et al. (2009) and the Technical Support Document for the calculation of benefit per-ton estimates (U.S. EPA 2008b):

1. Using an air quality model to estimate the changes in ambient $PM_{2.5}$ concentrations resulting from specified precursor emissions reductions under various scenarios and then calculating the total tons (of the precursor emissions) reduced under each scenario;
2. Using BenMAP to estimate the changes in incidence of the associated health effects and the monetized benefits of those incidence reductions under each scenario; and
3. Estimating national benefits per ton by dividing the national monetized benefits by the total tons of emissions reduced under each scenario.

In the current analysis, benefits per ton estimates are needed for four combinations of emission type and source category involving NO_x or SO_x:

- NO_x from EGUs (to be applied to changes in market-level NO_x emissions projected by IPM, and changes in emissions from auxiliary service);
- SO_x from EGUs (to be applied to changes in market-level SO_x emissions projected by IPM, and changes in emissions from auxiliary service);
- NO_x from mobile sources (to be applied to changes in NO_x emissions associated with transporting CCR waste to landfills); and
- SO_x from mobile sources (to be applied to changes in SO_x emissions associated with transporting CCR waste to landfills).

As described by Fann et al. (2009), "ambient $PM_{2.5}$ is a complex mixture of primary and secondarily formed particles, resulting from interactions in the atmosphere and physical transport of emissions of particulate matter precursors, including available SO_2, NO_x, and NH_3, meteorology (particularly temperature), and baseline levels and composition of $PM_{2.5}$" (Fann et al. 2009, p.170). NO_x and SO_x differ in their propensity for becoming $PM_{2.5}$. The benefits per ton estimates are based on the assumption that all fine particulates have the same potency for causing premature mortality (U.S. EPA 2011a).[59]

Fann et al. (2012) reported benefits per ton estimates for a variety of emission type/source category combinations, including all of those listed above, that are relevant to the current analysis, for the years 2005 and 2016. Although they are not reported in Fann et al. (2012), EPA also obtained benefits per ton estimates for each of these categories for the years 2020, 2025, and 2030 directly from one of the study co-authors.[60] For these additional years, the benefits per ton were calculated assuming the same change in ambient air quality as the author's forecast for 2016, but accounting for the 2020, 2025 and 2030 projected baseline mortality and population to estimate the change in mortality risk

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[59] Benefits per ton estimates are available for other pollutants, such as direct $PM_{2.5}$ emissions, but they were not included in this analysis because emissions factors were not available. The chemistry of PM formation is complex and nonlinear.

[60] Provided in personal communication with Charles Fulcher, EPA Office of Air Quality Planning and Standards (OAQPS), on October 19, 2012.

To be consistent with the rest of the analysis of the costs and benefits of the final ELGs, benefits per ton estimates are needed for each year from 2019 through 2042. Because the benefits per ton estimates for the years 2016, 2020, 2025, and 2030 are almost linear as a function of year, EPA interpolated benefits per ton values for the intermediate years (*e.g.*, between 2020 and 2025) and projected values for the years from 2031 through 2042 by linear regression, using (year, benefits per ton) data points for the years 2016, 2020, 2025, and 2030. Note, however, that the approximate linearity of the (year, benefits per ton) data points may be an artifact of the inability to project meteorological changes and thus changes in air quality for all years after 2016, noted above. Thus, additional uncertainty was generated by using benefits per ton estimates for the future years that did not account for meteorological and air quality changes.

Assuming that the geographic distribution of controlled emitting sources in a source category (*e.g.*, EGUs) and of emissions reductions in the current analysis are similar to the geographic distribution of emitting sources and emissions reduction in the analysis in Fann et al. (2012), EPA can derive a rough estimate of benefits from changes in air emissions by applying these benefits per ton estimates to the changes (in tons) of emissions resulting from compliance with the final rule. For example, the benefits from reduced emissions of NO_x from EGUs under Option D can be estimated by multiplying emissions avoided under the regulatory option by the appropriate benefits per ton value.

As noted above, NO_x and SO_x are known precursors to $PM_{2.5.}$ Several adverse health effects have been associated with $PM_{2.5,}$ including premature mortality, non-fatal heart attacks, hospital admissions, emergency department visits, upper and lower respiratory symptoms, acute bronchitis, aggravated asthma, lost work days and acute respiratory symptoms. All of these health effects were included in the estimation of benefits that went into the calculation of benefits per ton in Fann et al. (2012).

A very large percentage, 98 percent, of the total monetized benefits of reducing $PM_{2.5}$ concentrations are attributable to avoided premature mortality. The appropriate method for valuing the reductions in premature mortality and development of an accepted value for projected reduction in the risk of premature mortality is still a discussion in the economics and public policy communities. Fann et al. (2012) used data from Krewski et al. (2009), a study of mortality and long-term exposure to $PM_{2.5}$, to estimate the change in incidence of premature mortality associated with a given change in $PM_{2.5}$ concentrations. This study is one of several credible peer-reviewed long-term exposure studies that EPA has used in benefits analyses of $PM_{2.5}$.

When using long-term exposure studies, EPA has traditionally assumed that premature mortality avoided as a result of a reduction in $PM_{2.5}$ concentrations in a given year do not all occur in that year. Instead, EPA assumes that the avoided $PM_{2.5}$-related premature mortalities are distributed over a 20-year period, with most occurring in the earlier years. EPA values avoided premature mortality using VSL and then discounts that value back to the year of the analysis. Thus the numerator (the benefits) of the benefits per ton estimate for a given year is the value of morbidity avoided in that year plus the present discounted value of the stream of avoided premature mortalities over a twenty year period, discounted back to that year. For example, a benefits per ton estimate from Fann et al. (2012) for a ton removed in 2016 is the value of avoided morbidity in 2016 plus the present discounted value of the stream of avoided premature mortalities associated with that ton from 2016 to 2036, discounted back to 2016.

EPA obtained two sets of benefits per ton estimates for this analysis for the years 2005, 2016, 2020, 2025, and 2030: one set using a 3 percent discount rate and the other using a 7 percent discount rate.[61] All benefits per ton estimates for years 2019 through 2042 were further discounted back to the year 2015 (using a 3 percent or 7 percent discount rate, as appropriate). Because avoided premature mortalities are assumed to occur over a twenty-year period, and real income is likely to increase over time, these benefits per ton estimates reflect

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[61] Provided in personal communication with Charles Fulcher, EPA/OAQPS, on October 19, 2012

EPA's estimated increases in the value for mortal risk reductions with respect to increases in real income. The income growth adjustment factors used are those in BenMAP (Abt Associates Inc., 2012). *Table 7-5* summarizes the benefits per ton estimates EPA used for the different emission type and source category combinations involving NO_x and SO_2 in the analysis of the final rule.

Table 7-5: National Benefits per Ton Estimates for NOx and SO_2 Emissions (2013$/ton) from the Benefits per Ton Analysis Reported by Fann et al. (2012) [a, b, c]

Discount Rate	Year	EGU		Mobile Source (Onroad)	
		NOx	SO_2	NOx	SO_2
3%	2005	$3,791	$27,377	$4,633	$21,059
	2016	$5,475	$36,853	$7,687	$20,006
	2020	$5,686	$38,959	$8,108	$22,112
	2025	$6,107	$42,118	$8,845	$24,218
	2030	$6,528	$45,277	$9,582	$27,377
7%	2005	$3,475	$25,271	$4,107	$18,953
	2016	$4,844	$32,641	$6,949	$17,900
	2020	$5,159	$34,747	$7,476	$20,006
	2025	$5,475	$37,906	$8,002	$22,112
	2030	$5,897	$41,065	$8,634	$24,218

Source: U.S. EPA Analysis, 2015 based on Fann et al. (2012)

a. Provided for this analysis by Charles Fulcher, EPA/OAQPS on October 19, 2012.

b. Mortality benefits based on Krewski et al. (2009).

c. Estimation of benefits per ton for 2016, 2020, 2025, and 2030 were based on year 2016 emissions modeling.

7.1.3 CO_2

EPA estimated the global social benefits of CO_2 emission reductions using the social cost of carbon (SCC) estimates developed by the Interagency Working Group on the Social Cost of Carbon (IWGSCC, 2010, 2013a, 2013b, 2015a). This document refers to these estimates, which were developed by the U.S. government, as "SCC estimates." The SCC is a metric that estimates the monetary value of impacts associated with marginal changes in CO_2 emissions in a given year. It includes a wide range of anticipated climate impacts, such as net changes in agricultural productivity and human health, property damage from increased flood risk, and changes in energy system costs, such as reduced costs for heating and increased costs for air conditioning. It is used to quantify the benefits of reducing CO_2 emissions, or the disbenefit from increasing emissions, in regulatory impact analyses.

The SCC estimates were developed over many years, using the best science available, and with input from the public. Specifically, an interagency working group (IWG) that included EPA and other executive branch agencies and offices used three integrated assessment models (IAMs) to develop the SCC estimates and recommended four global values for use in regulatory analyses. The SCC estimates were first released in February 2010 and updated in 2013 using new versions of each IAM. The 2013 update did not revisit the 2010 modeling decisions with regards to the discount rate, reference case socioeconomic and emission scenarios, and equilibrium climate sensitivity distribution. Rather, improvements in the way damages are modeled are confined to those that have been incorporated into the latest versions of the models by the developers themselves and published in the peer-reviewed literature. The 2010 SCC Technical Support Document (TSD) (IWGSCC, 2010) provides a complete discussion of the methods used to develop these estimates and the current SCC TSD presents and discusses the 2013 update (including recent minor technical corrections to the estimates) (IWGSCC, 2013b). In July 2015, IWGSCC published technical correction to the estimates (IWGSCC, 2015a); EPA uses these most current values for the benefit estimates presented in this chapter.

The 2010 SCC TSD noted a number of limitations to the SCC analysis, including the incomplete way in which the IAMs capture catastrophic and non-catastrophic impacts, their incomplete treatment of adaptation and technological change, uncertainty in the extrapolation of damages to high temperatures, and assumptions regarding risk aversion. Currently IAMs do not assign value to all of the important physical, ecological, and economic impacts of climate change recognized in the climate change literature due to a lack of precise information on the nature of damages and because the science incorporated into these models understandably lags behind the most recent research. Nonetheless, these estimates and the discussion of their limitations represent the best available information about the social benefits of CO_2 reductions to inform benefit-cost analysis. The new versions of the models offer some improvements in these areas, although further work is warranted.

Accordingly, EPA and other agencies continue to engage in research on modeling and valuation of climate impacts with the goal to improve these estimates. The EPA and other agencies also continue to consider feedback on the SCC estimates from stakeholders through a range of channels, including public comments on Agency rulemakings that use the SCC in supporting analyses and through regular interactions with stakeholders and research analysts implementing the SCC methodology used by the IWG. In addition, OMB's Office of Information and Regulatory Affairs sought public comment on the approach used to develop the SCC estimates through a separate comment period that ended on February 26, 2014. See response to comment document (IWGCC, 2015b).

After careful evaluation of the full range of comments, the IWG continues to recommend the use of the SCC estimates in regulatory impact analysis. With the release of the response to comments, the IWG announced plans to obtain expert independent advice from the National Academy of Sciences to ensure that the SCC estimates continue to reflect the best available scientific and economic information on climate change. The NRC review will be informed by the public comments received and focus on the technical merits and challenges of potential approaches to improving the SCC estimates in future updates.

Concurrent with OMB's publication of the response to comments on SCC and announcement of the NRC process, OMB posted a revised TSD that includes two minor technical corrections to the current estimates. One technical correction addressed an inadvertent omission of climate change damages in the last year of analysis (2300) in one model and the second addressed a minor indexing error in another model. On average the revised SCC estimates are one dollar less than the mean SCC estimates reported in the November 2013 TSD. The change in the estimates associated with the 95th percentile estimates when using a 3 percent discount rate is slightly larger, as those estimates are heavily influenced by the results from the model that was affected by the indexing error.

The four SCC estimates are: \$13, \$46, \$68, and \$130 per metric ton of CO2 emissions in the year 2020 (2013 dollars).[62] The first three values are based on the average SCC from the three IAMs, at discount rates of 5, 3, and 2.5 percent, respectively. Estimates of the SCC for several discount rates are included because the literature shows that the SCC is sensitive to assumptions about the discount rate, and because no consensus exists on the appropriate rate to use in an intergenerational context (where costs and benefits are incurred by different generations). The fourth value is the 95th percentile of the SCC across all three models at a 3 percent

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[62] The SCC TSDs provide SCC in 2007 dollars, which are adjusted to 2013 dollars using the GDP Implicit Price Deflator. While the SCC values reported in *Table 7-6* have been rounded to two significant digits, unrounded numbers were used to calculate the CO_2 benefits.

discount rate. It is included to represent higher-than-expected impacts from temperature change further out in the tails of the SCC distribution. The SCC increases over time because future emissions are expected to produce larger incremental damages as economies grow and physical and economic systems become more stressed in response to greater climate change.

These estimates are then discounted back to the year 2015 using the same discount rate used to estimate the SCC. For internal consistency, the annual benefits are discounted back to net present value terms using the same discount rate as each SCC estimate (*i.e.* 5 percent, 3 percent, and 2.5 percent) rather than the discount rates of 3 percent and 7 percent used to derive the net present value of other streams of costs and benefits of the final rule.[63]

EPA estimates the dollar value of the CO_2-related benefits for each analysis year between 2019 and 2042 by applying the global SCC estimates, shown in *Table 7-6*, to the estimated reductions in CO_2 emissions under the final rule.

Table 7-6: Social Cost of Carbon Values (2013$/metric ton CO_2)

Year	5% Discount Rate, Average	3% Discount Rate, Average	2.5% Discount Rate, Average	3% Discount Rate, 95th Percentile
2019	$13	$45	$67	$130
2020	$13	$46	$68	$130
2021	$13	$46	$69	$140
2022	$14	$47	$70	$140
2025	$15	$50	$74	$150
2030	$18	$55	$80	$170
2035	$20	$60	$85	$180
2040	$23	$66	$92	$200

Source: IWGSCC, 2013b (values updated to 2013 dollars using GDP deflator (1.095)).

7.1.4 Estimating Total Air-Related Benefits

EPA calculated the monetized air-related benefits of the final rule, under options B and D, in any given year (discounted back to the year 2015) by (1) multiplying the tons of emissions avoided for a given emissions type/source category combination in that year by the benefits per ton for that emissions type/source category combination for that year, and then (2) summing the benefits across all emissions type/source category combinations. The total benefit for year y, then, is calculated using *Equation 7-1*.

Equation 7-1.

$$\sum_{j=1}^{9} (Tons\ avoided)_{y,j} \times BPT_{y,j}^{2015}$$

Where:

j = 1, 2, and 3 denote NO_x, SO_2, and CO_2, respectively, from market-level EGUs;
j = 4, 5, and 6 denote NO_x, SO_2, and CO_2, respectively, associated with auxiliary service;
j = 7, 8, and 9 denote NO_x, SO_2, and CO_2, respectively, associated with transportation; and
$BPT_{y,j}^{2015}$ is the present discounted value, discounted to the year 2015, of the benefits per ton for the jth emissions type/source category combination.

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[63] See more discussion on the appropriate discounting of climate benefits using SCC in the 2010 SCC TSD (IWGSCC, 2010).

The total present discounted value of benefits, discounted to the year 2015, PDV_{2015}, is calculated using *Equation 7-2.*

Equation 7-2.

$$PDV_{2015} = \sum_{y=2015}^{2042} \sum_{j=1}^{9} (Tons\ avoided)_{y,j} \times BPT_{y,j}^{2015}.$$

7.2 Results

Table 7-7 shows the estimated benefits from reductions in emissions of NO_x, SO_2, and CO_2 in each of several selected years for the two regulatory options EPA analyzed.

Table 7-7: Estimated Benefits from Reduced Air Emissions for Selected Years (millions; 2013$)[a]

Option	Year	3% Discount Rate	7% Discount Rate
Option B	2019[b]	$287.7	$266.3
	2020	$291.1	$270.0
	2025	$106.3	$102.4
	2030	-$46.5	-$41.4
Option D	2019[b]	$514.5	$482.2
	2020	$520.0	$488.8
	2025	$85.4	$88.4
	2030	$195.0	$186.2

Source: U.S. EPA Analysis, 2015

a. EPA used SCC values based on a 3 percent (average) discount rate to calculate total benefit values presented for both the 3 percent and 7 percent discount rate.

b. The benefits per ton values used for year 2019 benefit calculation is assumed to be the same as the 2020 benefits per ton values.

Table 7-8 shows the annualized benefits from reductions in emissions of NO_x, SO_2, and CO_2 for the two regulatory options EPA analyzed. EPA annualized benefit estimates to enable consistent reporting across benefit categories (*e.g.*, benefits from improvement in water quality). The total air-related benefits include benefits from CO_2 emissions reductions calculated using average SCC values (average at 2.5 percent, average at 5 percent, and the 95th percentile at 3 percent).

The annualized benefits of Options B and D are $110.2 million and $284.5 million, respectively, using a discount rate of 3 percent ($103.6 million and $248.6 million, respectively, using a discount rate of 7 percent).[64]

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[64] The 3 percent average SCC estimate was used to value reductions in CO_2 everywhere total benefits of the final rule are reported.

Table 7-8: Estimated Annualized Benefits from Reduced Air Emissions (Millions; 2013$)

ELG Option	Pollutant		3% Discount Rate	7% Discount Rate
Option B	NO_x		$12.7	$10.6
	SO_2		$45.0	$40.5
	CO_2	3% Avg	$52.5	$52.5
		5% Avg	$15.3	$15.3
		2.5% Avg	$77.4	$77.4
		3% 95th Percentile	$157.7	$157.7
	TOTAL	3% Avg	**$110.2**	**$103.6**
		5% Avg	**$73.1**	**$66.5**
		2.5% Avg	**$135.2**	**$128.6**
		3% 95th Percentile	**$215.5**	**$208.9**
Option D	NO_x		$63.1	$49.4
	SO_2		$81.6	$59.4
	CO_2	3% Avg	$139.8	$139.8
		5% Avg	$40.4	$40.4
		2.5% Avg	$206.8	$206.8
		3% 95th Percentile	$421.1	$421.1
	TOTAL	3% Avg	**$284.5**	**$248.6**
		5% Avg	**$185.1**	**$149.2**
		2.5% Avg	**$351.4**	**$315.6**
		3% 95th Percentile	**$565.8**	**$529.9**

Source: U.S. EPA Analysis, 2015

7.3 Implications of Revised Steam Electric Plant Loading Estimates

As described in *Section 1.4.3*, EPA revised its estimates of pollutant loadings in steam electric power plant discharges after completing the benefit analyses. Estimated air-related benefits do not depend on pollutant loadings to receiving waters and therefore the monetized benefit estimates provided in this Chapter are unaffected by revisions to steam electric plant loading estimates.

7.4 Limitations and Uncertainties

This analysis is subject to the standard sources of uncertainty found in any air pollution benefits analysis – uncertainties surrounding the estimated emissions changes, the estimated changes in air pollutant concentrations resulting from changes in emissions, the estimated concentration-response relationships between the air pollutant and various health effects in the exposed population, and the estimated value of each health effect avoided. There is additional uncertainty in the SCC estimates, which reflect the projection of future harm from climate change, and the benefits per ton estimates. More details about the limitations and uncertainties associated with the air-benefit analysis are discussed in *Table 7-9*.

Table 7-9: Limitations and Uncertainties in Analysis of Air-related Benefits

Issue	Effect on Benefits Estimate	Notes
Uncertainty in projecting the future harm from climate change.	Uncertain	When attempting to assess the incremental economic impacts of carbon dioxide emissions, the analyst faces a number of serious challenges. A report from the National Research Council (NRC, 2009) points out that any assessment will suffer from uncertainty, speculation, and lack of information about (1) future emissions of greenhouse gases, (2) the effects of past and future emissions on the climate system, (3) the impact of changes in climate on the physical and biological environment, and (4) the translation of these environmental impacts into economic damages. As a result, any effort to quantify and monetize the harms associated with climate change will raise serious questions of science, economics, and ethics and should be viewed as provisional. The Interagency Working Group on Social Cost of Carbon (IWGSCC, 2010, 2013a, 2013b) noted a number of limitations to the SCC analysis, including the incomplete way in which the integrated assessment models capture catastrophic and noncatastrophic impacts, the modeling of inter-regional and inter-sectoral linkages, their incomplete treatment of adaptation and technological change, uncertainty in the extrapolation of damages to high temperatures, and assumptions regarding risk aversion. The limited amount of research linking climate impacts to economic damages makes the interagency modeling exercise even more difficult. This said, the SCC estimates were developed using a defensible set of input assumptions that are grounded in the existing literature.
There is uncertainty associated with the effects of compliance costs on the forecast change in emissions from the electricity sector.	Uncertain	Compliance costs (capital, fixed or variable) will influence marginal generation decisions of plants affected by the final rule. In order to model the electricity market effects of the final rule, EPA made certain modeling assumptions that may influence the pattern of generation across the electricity sector, and therefore emissions. For example, EPA converted engineering capital costs to annual fixed operation and maintenance (O&M) costs in order to model the cost of complying with the final rule in IPM. See RIA Chapter 5, and Section 10.6: Executive Order 13211: Actions Concerning Regulations That Significantly Affect Energy Supply, Distribution, or Use for additional discussion of how modeling assumptions may influence the forecast air pollution changes from the IPM modeling. Differences between modeled and actual quantities of electricity generated and emission factors of dispatched generating units would affect the changes in air pollutants emissions and therefore the benefits resulting from these changes. EPA does not have information to quantify the magnitude of this uncertainty.

Table 7-9: Limitations and Uncertainties in Analysis of Air-related Benefits

Issue	Effect on Benefits Estimate	Notes
There is uncertainty associated with the effects of the Clean Power Plan rule	Uncertain	The final Clean Power Plan provides states considerable flexibility in developing state implementation plans to meet the rate or mass targets. This flexibility provides states great leeway to meet key priorities. However, it induces a considerable degree of uncertainty in what the future electric power market will look like and the overall economic impacts of the final ELGs. For example, states may choose to comply with the Clean Power Plan in ways that will lead to fewer or more coal-fired steam ELG plant retirements than the IPM runs would indicate. Such differences may have an important impact on dispatch profiles and emission changes.
EPA used a reduced form approach (benefits per ton) to value air-related benefits of emissions changes.	Uncertain	As Fann et al. (2012) note, "… implicit in the benefit per ton assessment is that the key attributes of the modeling — *e.g.* population distribution, source parameters, etc. — are not so different from the policy scenario as to affect the estimated benefits appreciably. Reduced form approaches assume a linear relationship between changes in emissions and benefits, an assumption that may not be valid for large changes in emissions" (Fann et al., 2012, p. 142).
EPA used year-specific benefits per ton estimates to derive values for each year within the analysis period.	Uncertain	Use of year-specific benefits per ton estimates from which to generate annual estimates introduces another layer of uncertainty into the analysis. In particular, because actual air quality modeling was carried out only for 2005 and 2016, the approximate linearity seen in the benefits per ton estimates for 2016, 2020, 2025, and 2030 may be an artifact of assuming that air quality remains constant at 2016 levels. The benefits per ton estimates for intermediate years also do not take into account the likely non-linearity involved. If each year-specific benefits per ton is uncertain, then an annual estimate incorporating benefits per ton-based estimates may be more uncertain. As a result, the annual estimates can be considered only rough estimates.

8 Benefits from Reduced Water Withdrawals

Steam electric power plants use vast quantities of water for ash transport and for operating wet FGD scrubbers.

By eliminating or reducing water used in sluicing operations or prompting the recycling of water in FGD wastewater treatment systems, the ELGs are expected to reduce water withdrawal from both surface waterbodies and aquifers. The reduction in water use depends on the regulatory option.[65] EPA estimates that power plants would reduce water withdrawals from between 45 billion gallons per year (0.12 million gallons per day) under Option and 209 to 222 billion gallons per year (0.57 to 0.61 million gallons per day) under Option E (see *Chapter 11* of *TDD* for details). The final BAT/PSES option (Option D) will reduce water withdrawals at steam electric power plants by 143 to 155 billion gallons per year (0.39 to 0.42 million gallons per day).

The section below discusses the benefits resulting specifically from reductions in groundwater withdrawals (*Section 8.1*). Benefits associated with surface water withdrawals are discussed qualitatively in Chapter 2 and in a separate report provided in the final rule record (see DCN SE05943).

8.1 Groundwater Withdrawals

Reduced water intake from groundwater sources by steam electric power plants are expected to result in increased availability of groundwater for local municipalities that rely on groundwater aquifers for drinking water supplies. These municipalities are expected to avoid the cost of supplementing drinking water supplies through alternative means, such as bulk drinking water purchases. The following sections describe EPA's estimate of reduced groundwater withdrawal benefits.

EPA estimated the benefits of reduced groundwater withdrawals based on avoided costs of purchasing drinking water during periods of shortages in groundwater supply.

8.1.1 Methods

EPA's analysis of the final ELG options (U.S. EPA, 2015b) indicate that one plant located in Nebraska will reduce the volume of groundwater withdrawn as a result of the ELGs. EPA estimated that the plant will avoid withdrawing a total of 21,971 gallons per day (8 million gallons per year) by converting to dry handling for its bottom ash under Options D and E. Because the state is potentially or currently water-stressed (Tetra Tech, 2011), the ELGs are likely to generate benefits from improved groundwater recharge. To estimate the value of improved groundwater supply, EPA relied on state-specific prices of bulk drinking water supplies, since municipalities may need to purchase supplementary supplies in response to groundwater shortages arising from excessive withdrawals. EPA recognizes that the assumption that a reduction in groundwater withdrawals in the water-stressed states may result in reduced groundwater shortages is somewhat speculative, but used this assumption to provide screening-level estimates of the potential benefits.

To estimate the monetary value of reduced groundwater withdrawal, EPA relied on current state-specific water prices ($1,192.06 per acre/foot for Nebraska). For each affected plant and regulatory option, EPA

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[65] Depending on the BAT/PSES technology basis for fly and bottom ash wastewater, the regulatory option may eliminate or reduce water use associated with current wet sluicing operating systems at steam electric power plants. Specifically, reductions in intake flow are expected to occur at plants which convert to dry handling or recycle FGD wastewater .

multiplied the reduction in groundwater withdrawal (in gallons per year) by the estimated price of drinking water per gallon. EPA used a conversion factor of 325,851 to convert acre foot to gallons.

8.1.2 Results

Table 8-1 shows estimated annual benefits from reduced groundwater withdrawals. The annual benefits from the BAT/PSES option (Option D) for existing sources are $0.02 million using a 3 percent discount rate ($0.02 million using a 7 percent discount rate).

Table 8-1: Estimated Annualized Benefits from Reduced Groundwater Withdrawals (Millions; 2013$)

Regulatory Option	Reduction in Groundwater Intakes (million gallons per year; full implementation)	3% Discount Rate	7% Discount Rate
Option A	0.0	$0.00	$0.00
Option B	0.0	$0.00	$0.00
Option C	0.0	$0.00	$0.00
Option D	8.0	$0.02	$0.02
Option E	8.0	$0.02	$0.02

Source: U.S. EPA Analysis, 2015

8.1.3 Implications of Revised Steam Electric Plant Loading Estimates

As described in *Section 1.4.3*, EPA revised its estimates of pollutant loadings in steam electric power plant discharges after completing the benefit analyses. Estimated water withdrawal benefits do not depend on pollutant loadings and therefore the monetized benefit estimates provided in this Chapter are unaffected by revisions to steam electric plant loading estimates.

8.1.4 Limitations and Uncertainties

Table 8-2 summarizes the limitations and uncertainties in the analysis of benefits associated with reduced groundwater withdrawals.

Table 8-2: Limitations and Uncertainties in Analysis of Reduced Groundwater Withdrawals

Uncertainty/Assumption	Effect on Benefits Estimate	Notes
EPA assumed that municipalities would need to replace lost groundwater supplies with bulk drinking water purchases.	Uncertain See below.	Municipalities may not need to replace groundwater withdrawn by steam electric power plants (in which case the benefits of the ELG may be overstated), or they may choose to replace the groundwater through other means, such as desalinization (in the case of Florida, in which case the benefits of the ELG may be understated).
EPA assumed a direct relationship between groundwater withdrawals in water-stressed states and groundwater shortages, *i.e.*, that reducing demand for limited groundwater supplies would result in avoided costs for purchased water.	Overestimate	EPA assumed that demand for additional water supply exists in the affected areas (Florida and Nebraska) due to potential draughts. However, the extent of this demand is uncertain.

Table 8-2: Limitations and Uncertainties in Analysis of Reduced Groundwater Withdrawals

Uncertainty/Assumption	Effect on Benefits Estimate	Notes
Affected aquifer characteristics	Uncertain	If the affected aquifers are used for private wells only, the estimated benefits of improved groundwater recharge could be under- or overstated, depending on households WTP for protecting groundwater quantity.

9 Benefits from Avoided Dredging Costs

EPA expects that the final rule will reduce discharge loads of various categories of pollutants including total suspended solids (TSS), thereby reducing the rate of sediment deposition to affected waterbodies, 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, Haverkamp, and Chapman, 1985). In many cases, costly periodic dredging is necessary to keep them passable. The final steam electric ELG could provide cost savings to government and private entities responsible for maintenance of navigable waterways by reducing the dredging volume.

Reservoirs serve many functions, including storage of drinking and irrigation water supplies, flood control, hydropower supply, and recreation. Streams can carry sediment into reservoirs, where it can settle and cause buildup of silt layers over time, at a recorded average rate of 1.2 billion kilograms per reservoir every year (USGS, 2007b). Sedimentation reduces reservoir capacity (Graf, Wohl, Sinha, and Sabo, 2010) and the useful life of reservoirs unless measures such as dredging are taken to reclaim capacity (Clark, et al., 1985). EPA expects that the final ELG will provide cost savings by reducing dredging activity to reclaim capacity at existing reservoirs.

EPA estimates that the final ELG would result in modest cost savings from reducing the amount of sediment dredged from navigational waterways and reservoirs affected by pollutant discharges from steam electric power plants. Under Option D, benefits from reduced navigational waterway dredging are less than one thousand dollars, with both 3 and 7 percent discount rates; benefits from reduced reservoir dredging are less than two thousand dollars, with both 3 and 7 percent discount rates. EPA has revised sediment loadings following the completion of the benefit analysis However, because sediment loadings changed by approximately 1 percent the overall effect on the estimated benefits from reduced dredging of navigational waterways and reservoirs is likely to be trivial.

Appendix K provides a more detailed description of the methodology and results of this analysis. This appendix presents EPA's analysis of the avoided dredging costs for navigable waterways and reservoirs under the five regulatory options. First, it describes EPA's analysis of historic dredging locations and frequency. Next, it presents EPA's approach for estimating sediment deposition and removal in dredged waterways and reservoirs under the ELG regulatory options and associated costs. It then presents estimated benefits.

10 Benefits from Enhanced Marketability of Coal Combustion Residuals

EPA expects that installation of waste stream treatment technologies to comply with final ELGs will affect the type of coal combustion residue (CCR) by prompting plants to convert from wet handling of fly ash, bottom ash, and/or flue gas desulfurization (FGD) waste to dry handling. Relative to wet ash, dry ash's chemical and physical properties make it more suitable for re-use in a variety of applications like structural fill, concrete, and wallboard (U.S. EPA, 2015d; American Coal Ash Association, 2012). This change would in turn allow plants to more readily market CCR to beneficial uses.

There are two main economic benefits to society of re-using CCR. First, plants that are able to beneficially re-use CCRs are able to offset the CCR disposal costs (*e.g.*, trucking and landfills) that EPA counted in its cost and economic impact analyses of this final rule. These avoided costs are net of *added* costs that some plants may incur in preparing dry CCRs for reuse. Second, by replacing raw or virgin inputs with re-used CCR materials during the production of structural fill and concrete, society avoids the need for and cost of extracting and preparing the raw or virgin inputs. These benefits include both direct costs (*e.g.*, operating machinery, costs of transport), and indirect costs (*e.g.*, downstream environmental benefits).

This Chapter describes the methodology EPA used to estimate the avoided cost benefits resulting from the enhanced marketability of CCR. The approach builds on the methodology EPA used in analyzing changes in beneficial use of CCRs under the final RCRA *Final Rule for Disposal of Coal Combustion Residuals Generated by the Electric Utility Industry* (U.S. EPA, 2014).

10.1 Methods

10.1.1 Beneficial Use Applications

The methodology focuses on two CCR wastestreams, and two end uses that may be affected by the final ELGs:[66] (1) fly ash as a substitute for Portland cement in concrete production and (2) fly- and bottom ashes as substitutes for sand and gravel in fill applications (*Table 10-1*).[67]

In this analysis, EPA assumes that the ELGs do not materially affect the total quantity of CCR generated by steam electric power plants but instead change only the relative shares of the CCR handled dry instead of wet. Following the central assumptions of EPA's cost and economic impact analyses for this rule (U.S. EPA, 2015c), EPA assumes that plants generate a constant amount of CCR each year in the analytic time period.

Table 10-1: Applicable Beneficial Use Applications of CCRs, by CCR Category

CCR Category	Beneficial Use Application	
	Concrete Production	Fill
Fly ash	✓	✓
Bottom ash		✓

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[66] EPA does not expect the final ELGs to affect the quantity or handling of FGD gypsum, and this CCR use is therefore excluded from the benefit analysis.

[67] Note that this assumed pattern simplifies actual uses. The American Coal Ash Association (ACAA) reports other important uses (*i.e.*, each more than 1 million short tons in 2012) for fly ash, bottom ash, and FGD gypsum, including waste stabilization (fly ash), blended cement/feed for clinker (fly ash, bottom ash, and FGD gypsum), and mining applications (fly ash, FGD gypsum) (http://www.acaa-usa.org/Portals/9/Files/PDFs/revisedFINAL2012CCPSurveyReport.pdf).

10.1.2 Marketable CCR by State

The demand for concrete and fill constrains the extent to which steam electric power plants will be able to shift CCRs from disposal to beneficial use. Transportation costs are another main constraint and make marketing of CCR across long distances less likely. USGS Minerals Commodity Summaries (*e.g.*, Bolen, 2014; van Oss, 2013) show that both sand and cement production vary across regions of the United States; thus, Steam Electric facilities in different parts of the country likely face different markets for CCR.

CCR end use sites include a mix of industrial facilities (*e.g.*, to produce cement) and dispersed sites (*e.g.*, as structural fill). Without precise information about the location of these beneficial use sites within regions, EPA used sand and cement production within the state surrounding a plant to approximate the regional market demand each plant may face in marketing dry CCR. This approach assumes that plants only market their CCR to sites within the plant's state, and that state-level demand constrains the total amount of CCR that steam electric power plants in that state, as a group, will be able to market to various end uses. To determine the maximum quantity of CCRs that steam electric power plants located in a given state will be able to market ("marketable CCRs"), EPA compared state-level estimates of supply and demand for CCR.[68] Procedures to estimate demand and supply are described below. Due to heterogeneity in state sizes, this assumption implies the geographic extent of, and volume of, CCR markets vary across states.

10.1.2.1 Demand for CCR

EPA assumed that the annual quantities of end products (*e.g.*, cement, and construction sand and gravel) produced and used in the United States represent the maximum annual demand for CCR in those applications, accounting for the share of the end products that may be replaced with CCR.

- ***Total End Product Production***. EPA estimated *concrete* and *fill* production based on U.S. Geological Survey "Minerals Commodity Summaries," and developed 3-year average production statistics for *cement* and *construction sand and gravel*, respectively (Bolen, 2011, 2012, 2013, 2014; van Oss, 2009, 2010, 2013). These are the same sources as used for the final CCR rule analysis, but with more current data. In estimating production, EPA used state-level sand and gravel production statistics directly (*e.g.*, Bolen, 2010). Annual cement production statistics are presented by multi-state regions, and separately report production for Portland and masonry cements (*e.g.*, Van Oss, 2010). Because Portland cement constitutes the majority of total cement production by weight (97% in 2013), EPA used total cement production as a proxy for Portland cement production. EPA downscaled regional cement production statistics to individual state(s) by state shares of regional population (US Census, 2012).
- ***End Product Input Replaceable with CCR.*** For each end product, EPA then estimated the portion of total production that could be replaced with CCR. For cement, EPA assumed that:
    - *Fly ash could replace 25% of cement used in concrete*. This percentage represents the low end of several replacement rates reported in industry literature while remaining consistent with the final CCR rule and other federal government documents. For example, ERMCO (2013) reports that fly ash additives constitute 21.7% of cement in the United States, and We Energies (2013, p. 65) concluded that fly ash could be substituted for up to 40% of Portland concrete by weight in making structural grade concrete. Government replacement rate

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[68] The CCR Final Rule approach (Appendix S) used linear programming to estimate incremental changes in beneficial reuse due to the rule, accounting for county-level capacity constraints (maximum demand).Although our state-level market approximations more coarsely delineate markets, they also serve to constrain maximum reuse to estimated market capacity.

estimates tend to be somewhat lower than industry estimates; for example, the CCR rule assumed that "that fly ash makes up no more than 30% of …cementitious material" (Appendix S in US EPA, 2014), based on resources from US EPA (2008)[69], and the Federal Highway Administration Materials Group recommends a substitution rate of no more than 15 to 25 percent in pavement applications (FHWA, 2015).

- *73 percent of cement is used in ready-mix concrete* (ERMCO, 2013).Of the cement that fly ash can replace, only a portion is used in concrete; mortar and grout are other uses for cement.

For fill, EPA assumed that:

- *Fill is 36% of total sand and gravel production by state*. In 2012, 36% of national construction sand and gravel production was used in fill and fill-like applications (Bolen, 2013), which include concrete aggregates (including concrete sand); asphaltic concrete aggregates and other bituminous mixtures; road base and coverings; fill; and snow and ice control.
- *Beneficial reuse of CCRs in fill carries no stigma, and could potentially replace 100 percent of sand/gravel use as fill.* Consistent with the analysis of the CCR final rule, EPA assumed no stigma around the reuse of CCRs in fill applications. EPA notes, however, that there may remain some potential for the public to negatively perceive CCR re-used in fill or concrete because they are unfamiliar with CCR and/or with re-use practices, but consume media information that incorrectly characterizes these products and practices as "toxic" (U.S. EPA, 2010d) . Because EPA did not identify information estimating the national extent or impact of stigma around CCR reuse, EPA assumed no stigma in residential applications. This approach is consistent with the non-hazardous determination applied in the Final CCR Rule, which is designed to avoid stigma around uses of "hazardous" products. To the extent that stigma or perceptional effects does exist and leads to reduced marketability of CCRs, the analysis may over-state the re-use of CCRs in some applications (*e.g.*, residential contexts).

10.1.2.2 CCR Supply

- ***Baseline Production***. EPA estimated state-level baseline CCR supply by ash type, including (1) the sum of plant-level dry fly and bottom ash production marketed, as reported by Steam Electric plants located within the state in response to the 2010 Questionnaire for the Steam Electric Power Generating Effluent Guidelines (U.S. EPA, 2010a); and (2) The state-level sum of additional CCRs available for beneficial reuse due to the final CCR rule. The CCR final rule analysis projected that in 2025, the 3-year rolling average of the annual increase in national CCR beneficial uses will total 0.26 million tons of fly ash in concrete, and 5.65 million tons of CCRs in structural fill.[70] EPA allocated these national total supply of CCR to states with baseline cement and sand production. Using population as a proxy for fill and concrete use (and thereby, a proxy for production), EPA allocated the additional CCR to states based on each state's population.
- ***Change in Dry CCR Supply due to Final Steam Electric ELGs***. EPA used data on annual plant-level changes in the quantity of CCRs handled dry, by category – fly ash and bottom ash – and which could

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[69] U.S. EPA (2008). Study on Increasing the Usage of Recovered Mineral Components in Federally Funded Projects Involving Procurement of Cement or Concrete to Address the Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users, Report to Congress, June 3, 2008, EPA530-R-08-007.

[70] CCR RIA, Exhibit 5-L.

be more readily marketed for beneficial use after making changes to meet the final ELGs under each of the regulatory options (see *TDD* for details).[71]

Consistent with the screening-level cost and economic impact analyses for the final rule which assume that steam electric power plants generate a constant amount of electricity throughout the analysis period (see RIA; U.S. EPA 2015c), EPA assumed that steam electric power plants will produce the same quantity of dry CCRs every year in the analysis period, beginning in the technology implementation year. EPA determined the amount of plant-level changes in fly- and bottom ash CCRs marketable to the two beneficial use categories assuming that fly ash is first marketed to concrete, as it is the use with higher market value, and then the remaining fly and bottom ash CCRs marketed to fill, as possible given remaining demand.

10.1.2.3 Marketable CCR

Thirty six states produced cement in 2010, 2011, or 2012 (van Oss, 2009; 2010; 2013). Given baseline CCR supply, EPA estimated that additional CCR production due to conversion to dry ash handling systems to meet the final ELGs would be marketable in 14 (39 percent) of these states. Note that none of the steam electric power plants expected to increase dry CCR production due to the ELGs are located in states without cement production in the baseline.

All 50 states produce sand and gravel, and EPA estimated that the CCR supply (from existing marketing of CCR by steam electric power plants and projected CCR reuse) exceeds demand for fill in only one state (West Virginia). In all other states, demand data suggest that steam electric power plants can market all the additional CCR handled dry.

Table 10-2 reports “marketability” estimates for all states combined. Marginal changes in dry CCR represent approximately 5 percent of unmet demand for CCR as a substitute for Portland cement in concrete and 2 percent of unmet demand for CCR as a substitute for sand and gravel in fill. EPA expects that some plants will market CCR to both cement and fill, and that a lack of demand for fly ash in cement will induce many to market fly ash to fill. Nearly all of the expected conversions to dry-handled fly and bottom ash could potentially be marketed for beneficial reuse within the plant’s state.

Table 10-2: State-level Market Approximation (Short Tons).

	Baseline Production		Marketable Changes due to ELGs	
Application	**Production**	**Unmet Demand (% of production)**	**Fly Ash (% Total ΔCCR)**	**Bottom Ash (% Total ΔCCR)**
Concrete	13,400,062	3,277,184 (24%)	162,491 (12.2%)	NA
Fill	320,701,683	312,705,505 (98%)	1,166,260 (87.8%)	4,314,946 (91.7%)

Source: U.S. EPA Analysis 2015

EPA excluded from subsequent valuation of tallied “incremental” marketable CCR any changes that occur at steam electric power plants which already market the wet ash in the baseline, and only calculated benefits associated with plants that do not currently market their CCR wet. While these plants may convert to dry handling and may therefore find it easier to market their CCR in the future, EPA assumed for simplicity that the amount of ash they could market for beneficial use will not change as a result of this conversion. As a

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[71] Fly ash tonnages are a dry-basis (not moisture conditioned), and were only calculated for steam electric units flagged for transport and disposal costs, excluding those units flagged for costs associated with additional conveyance capacity. Bottom ash tonnages were estimated for all bottom ash handling conversions excluding units marked for bottom ash management costs. Tonnage estimates include the CCR population; conversions at plants flagged as a fly ash or bottom ash dry conversion under the CCR rule were zeroed.

result of this assumption, the analysis values 100 percent of fly ash conversions marketed to concrete, and 93 percent of fly ash and bottom ash conversions marketed to fill.

10.1.3 Value to Society from Re-Using CCR

Replacing virgin materials like fill and cement with CCR wastes avoids some costs while introducing other costs. EPA used the social cost accounting framework summarized in ***Error! Reference source not found.*** to track benefits and costs of CCR re-use, notably changes in production and disposal pre- and post-ELGs. The remainder of this section provides more detail on cost and benefit categories.

Figure 10-1: Cost Accounting Framework for the Beneficial Reuse Analysis.

Without Reuse	With Reuse	Net Change	Valuation Framework
Raw Materials (sand, cement)			
Extraction/ mining	No extraction/ Mining	↓ Raw material extraction	Life Cycle Analysis[a]
Processing	No processing	↓ Raw materials processing	
Transport to market	No transport to market	↓ Raw materials transportation	
CCR from Steam Electric Power Generation			
Prepare CCR for disposal	Beneficiate CCR for re-use	↑ Beneficiation	Estimate beneficiation costs
Transport SE CCR to disposal site	Transport SE CCR to reuse site	No net change in SE CCR transport costs[b]	Qualitative uncertainty analysis
Disposal	No Disposal	↓ Disposal costs to meet SE ELG	Estimate avoided disposal costs

a: As was done in the analysis of the final CCR rule, EPA selected the LCA approach to estimate costs that society avoids by replacing virgin materials with CCR, including environmental impacts. The market value of avoided raw materials is an alternative cost proxy which captures some, but not all of these production costs. LCA captures some, but not all costs from a market price framework, and thereby is also an approximate avoided social cost.

b: On net, EPA assumed no change in transportation cost between the base case and policy scenario. In the base case, some plants dispose of CCR on-site, while others dispose of it off-site. Re-use applications are assumed to occur off-site; however, EPA also assumed that, on net to society, total costs of transportation to disposal and re-use sites are approximately equal given our in-state market framework.

<u>Avoided Costs</u>. Re-using CCRs avoids several costs, including the environmental costs of extracting virgin materials and costs to steam electric power plants of disposing of their CCR.

- ***Compliance cost offset***. By redirecting the CCR to beneficial re-use rather than disposing of it, steam electric power plants can avoid disposal O&M costs attributed to meeting the ELGs in the economic impact analysis (see RIA; U.S. EPA 2015c). EPA's analysis of the Final CCR Rule assumed plants marketing CCR could avoid certain per-ton transportation and disposal costs based on the volume of CCR marketed, but that plants could not offset certain other costs of the rule (*e.g.*, general liability insurance required under the CCR rule, but not under the Steam Electric ELGs). For this Final Rule, EPA also assumed plants could not offset capital costs associated with disposal systems (*e.g.*, landfills), but could offset O&M costs include tipping fees at off-site landfills. In this analysis, EPA assumes Steam Electric power plants market 100% of dry CCR produced following the rule. Since EPA assumes that plants that market dry CCR are able to re-use 100% of ash by volume, EPA assumed plants could offset 100% of these O&M costs. To the extent that plants may not market 100% of ash in all years, this assumption produces an upper bound estimate of potential cost offsets due to beneficial reuse.

- ***Production cost offset***. This offset is the avoided cost of virgin materials costs[72] resulting from using CCR in place of the virgin materials (*e.g.*, Portland cement, sand and gravel). Depending on who uses the CCR for beneficial purposes, these cost offsets (transfers) may accrue to the steam electric power plant, the secondary CCR user who either paid for or received the CCR for free, a third-party reseller, etc.
- ***Environmental benefits***. By avoiding the production of virgin materials needed for Portland cement and fill, society also gains a reduction in total environmental damages associated with extracting, transporting, and processing these raw materials (*e.g.*, air emissions and resource consumption). Life Cycle Analysis (LCA) is a framework to assess the total environmental impact of a product based on an inventory of energy and material inputs and outputs associated with each step in producing the product. Typically, LCA addresses raw material acquisition, materials manufacture, production, use/reuse/maintenance, and waste management (SAIC, 2006), and estimates environmental impacts per unit of product produced (*e.g.*, changes in energy consumption, water consumption, and air pollutant emissions). To estimate the total environmental benefits of avoided Portland cement and fill production in this analysis, EPA applied the existing LCA impacts for cement and sand and gravel used in EPA's CCR Final Rule.

  Table 10-4 lists environmental impacts per ton of avoided virgin material, and *Table 10-5* lists the estimated unit values of the avoided economic impacts of these environmental impacts. EPA applied benefit transfer of unit economic values based on the Final CCR Rule's LCA approach, the Social Cost of Carbon (IWGSCC, 2013b), and human health benefits from reducing emissions of $PM_{2.5}$ precursors (U.S. EPA based on Fann et al., 2012).

As shown in ***Error! Reference source not found.***, *production cost offsets* overlap with benefits from *avoided life-cycle impacts.* Specifically, the life-cycle impact framework captures many of the energy, water and other production costs that fill and concrete producers can avoid by re-using CCR products and avoiding the production of virgin materials. Since the life-cycle framework also captures avoided environmental impacts of production, the remainder of this analysis reports only the monetized benefits from the life-cycle framework to avoid potentially double-counting benefits.

Additional Costs. Steam electric power plants that market CCRs for beneficial re-use do so when the re-use is economically preferable to disposal. Some plants may find it necessary to undertake additional preparation of dry CCRs before beneficial use (*e.g.*, to bring CCR to ASTM standards), or may need to consider the cost of transporting CCR to a beneficial use destination. There is uncertainty in the degree to which steam electric power plants incur one or more of these additional costs. To provide a conservative estimate of avoided costs (and benefits), EPA included additional costs for beneficiation.

- *Beneficiation of fly ash prior to use in concrete*: EPA assumed that 13 percent of fly ash requires beneficiation prior to use in concrete.[73] Electric Power Research Institute (2005) reports a range of beneficiation costs per ton of fly ash; the CCR Final Rule analysis estimated that a reasonable central tendency value for the cost of beneficiation is approximately $10 per ton (in year 2004$). EPA updated this cost to 2013 dollars and applied this cost to 13 percent of marketable fly ash CCRs at each steam electric power plant.

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[72] For reference, the 3-year average (2008 to 2012) market price of sand and gravel used as fill is $4.36/ton (range: $2.38 - $9.30 by state) (van Oss/USGS, 2010, 2011, 2013). The 3-year average (2008 to 2012) market price of Portland cement is $44.50/ton ($76.24 - $148.02 by state) (Bolen, 2011, 2012, 2013, 2014).

[73] In the Final CCR rule analysis document, ORCR cites personal communication with David Goss, ACCA (June 25, 2008) as the source of this assumption.

EPA calculated monetary values of estimated changes in beneficial use of marketable CCRs based on the avoided costs by steam electric power plants, as well as the avoided resource impacts from displacing virgin materials. *Table 10-3* lists rates and ratios for avoided costs and additionally-incurred costs associated with re-using CCR for beneficial uses. *Table 10-4* and *Table 10-5* list the quantity and value of avoided resource and environmental impacts.

Table 10-3: Economic Value of CCR Handling Costs per Unit (2013$).

Cost Type	Beneficial Use	Cost/Benefit
Avoided Costs of Disposal	Sand and Gravel Used as Fill; Concrete	Varies by Steam Electric plant[a]
Additionally Incurred Costs of Beneficiation	Concrete	$11.95 per ton[b]

a. EPA estimated the annual cost of CCR disposal by Steam Electric plant and year (U.S. EPA, 2015).

b. Electric Power Research Institute (2005).

Table 10-4: Avoided Resource and Environmental Impacts per Ton of Virgin Material Produced.

Impact Category		Portland Cement[a,c]	Fill[b,c]
Energy (MMBtu)		3.52 - 3.62*	0.04
Water (gal)		201 – 246,947*	1,208
Air Emissions	Greenhouse gases (tons)	0.90 – 0.93*	0.0032
	NOx (tons)	0.0019	2.68×10^{-5}
	SOx (tons)	2.43×10^{-4}	8.50×10^{-6}

a. Assumptions are based on Final CCR rule analysis. For energy use, water use, greenhouse gases, carbon monoxide, and PM10 associated with portland cement, the range of values presented in this Table reflect data from Ecoinvent v2.2 as included in SimaPro 7.2 and the National Renewable Energy Laboratory's U.S. Life Cycle Inventory Database, the latter of which is available at http://www.nrel.gov/lci/. The Portland cement values for NOx, PM2.5, SOx, and mercury were all derived from emissions data presented in U.S. EPA, Regulatory Impact Analysis: Amendments to the National Emission Standards for Hazardous Air Pollutants and New Source Performance Standards (NSPS) for the Portland Cement Manufacturing Industry Final Report, August 2010. The value for lead was derived from Ecoinvent v2.2 as included in SimaPro 7.2.

b. Assumptions are based on Final CCR rule analysis. Values for fill reflect the average of values for sand and clay from Ecoinvent v2.2 as included in SimaPro 7.2.

* Denotes cases in which EPA used the lower limit of the range for this scoping analysis.

Table 10-5: Economic Value of Avoided Resource and Environmental Impacts per Unit of Impact (2013$).

Impact Category	Portland Cement	Fill
Energy ($/MMBtu)[a]	$4.94	$19.15
Water ($/gal)[b]	$0.00003	
Greenhouse gases ($/ton)[c]	$36 to $62	
NOx ($/ton)[d]	$5,694 to $8,836	$5,694 to $8,836
SOx ($/ton)[d]	$43,856 to $68,109	$43,856 to $68,109

a. Assumptions are based on Final CCR rule analysis. Derived from U.S. Department of Energy, Energy Consumption by Manufacturers, May 2013. Table 7.2. This is the same data source as that used for the final CCR rule, updated to 2013$ using GDP deflator.

b. Assumptions are based on Final CCR rule analysis, updated to 2013$ using GDP deflator. Value provided by H. Scott Matthews, Professor of Civil and Environmental Engineering and Engineering and Public Policy at Carnegie Mellon University and Research Director of Carnegie Mellon University's Green Design Institute, October 18, 2011.

c. Values shown are the range of yearly Social Cost of Carbon values from 2015 to 2042, using the Average Value at 3% discount rate (adjusted to 2013$ and converted from *tonnes* to *tons*). Values are derived from Interagency Working Group on Social Cost of Carbon, United States Government, Technical Support Document: Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866, 2013 (revised June 2015). EPA also calculated benefits using the 5% average ($10 to $22), 2.5% average ($50 to $85), and 3% 95th percentile ($85 to $188) SCC estimates.

d. Values shown are the range of yearly benefit per ton estimates (2015 to 2043) linearly interpolated and extrapolated from BenMap benefit per ton estimates for 2016, 2020, 2025, and 2030. Benefit per ton unit impacts were provided in personal communication with Charles Fulcher, EPA/OAQPS, on October 19, 2012 and updated to 2013$ using GDP deflator. EPA applied values for the "Cement Kilns" sector to Portland cement, and values for the "area sources" aggregate sector to fill. Values shown are the central tendency by sector, at 3% discount rate.

10.2 Results

Table 10-6 summarizes the estimated change in dry and marketable CCRs beneficially used in concrete and fill applications due to final ELGs and other regulatory options, for steam electric power plants *not* marketing wet ash in the baseline. The analysis suggests that most marketable CCRs would be beneficially used in fill applications.

Table 10-6: Estimated Beneficial Use Applications of CCRs, by CCR Category

ELG Option and CCR Category	Beneficial Use Application (1,000 short tons)	
	Concrete	Structural Fill
Option A or Option B		
Fly ash	162	1,166
Bottom ash	NA	0
Total	**162**	**1,166**
Option C		
Fly ash	162	1,166
Bottom ash	NA	2,813
Total	**162**	**3,979**
Option D or Option E		
Fly ash	162	1,166
Bottom ash	NA	3,763
Total	**162**	**4,929**

Table 10-7 reports the estimated life cycle benefits of avoiding virgin materials in concrete and fill production. *Table 10-8* reports the estimated annualized economic value of increased marketable CCRs by value category. Relative changes in total CCR beneficial use and total life cycle impacts under the final ELGs are consistent with the projected effects of the CCR rule on beneficial reuse (shown in last column of the table; U.S. EPA, 2014).

Table 10-7: Annual Avoided Resource and Environmental Impacts Given CCR Reuse in Concrete and Fill Applications.

Impact Category	Fly Ash	Bottom Ash	Option Total	CCR RIA, 2030 3-yr rolling avg
Option A or Option B				
Energy (MMBtu)	618,618	0	618,618	910,000
Water (million gal)	1,442	0	1,442	21,000
Greenhouse gases (tons)	149,974	0	149,974	75,000
NOx (tons)	340	0	340	310
SOx (tons)	49	0	49	160
Option C				
Energy (MMBtu)	618,618	112,536	731,154	910,000
Water (million gal)	1,442	3,399	4,840	21,000
Greenhouse gases (tons)	149,974	9,003	158,977	75,000
NOx (tons)	340	75	415	310
SOx (tons)	49	24	73	160
Option D or Option E				
Energy (MMBtu)	618,618	150,515	769,133	910,000
Water (million gal)	1,442	4,546	5,987	21,000
Greenhouse gases (tons)	149,974	12,041	162,015	75,000
NOx (tons)	340	101	441	310
SOx (tons)	49	32	81	160

Note: Values in this table represent annual changes in a full-compliance year (*e.g.*, starting in 2023).

Table 10-8: Annualized Economic Value of Estimated Changes in Beneficial Use (Million 2013$) [a,b].

Regulatory Option	Impact Category	3%	7%
Option A or Option B	Avoided Disposal Costs to Steam Electric Plants	$0.80	$0.68
	Beneficiation Costs	-$0.21	-$0.16
	Avoided Life Cycle Costs of Virgin Materials	$10.74	$13.79
	Net Social Value	**$11.33**	**$14.31**
Option C	Avoided Disposal Costs to Steam Electric Plants	$13.03	$10.87
	Beneficiation Costs	-$0.21	-$0.16
	Avoided Life Cycle Costs of Virgin Materials	$12.18	$15.43
	Net Social Value	**$25.00**	**$26.14**
Option D or Option E	Avoided Disposal Costs to Steam Electric Plants	$18.49	$15.46
	Beneficiation Costs	-$0.21	-$0.16
	Avoided Life Cycle Costs of Virgin Materials[c]	$12.52	$15.81
	Net Social Value	**$30.80**	**$31.11**

Notes: a. Annualized over 24 years (2015 - 2042). Values escalated using CCI and GDP through 2022; thereafter, assume no real change in prices above inflation. Avoided disposal costs to steam electric power plants include are annual O&M costs. B.

b. EPA used SCC values based on a 3 percent (average) discount rate to calculate total benefit values presented for both the 3 percent and 7 percent discount rate.

c. EPA also estimated life cycle benefits for Options D or E, at other SCC estimates (IWGSCC, 2013 (revised June 2015)). Results of LCA benefits at 5% average, 2.5% average, and 3% 9th percentile SCC estimates range from $5.12 million (5% average) to $19.90 million (3% 95th percentile) when discounted at 3%, and from $3.81 million (5% average) to $14.87 million (3% 95th percentile).

As shown in *Table 10-8*, for Options requiring both fly and bottom ash technologies, much of the annualized economic value from changes in beneficial use comes from avoided disposal costs incurred by steam electric plants, even after accounting for any increased beneficiation costs.

The estimates above translate into net annualized benefits of approximately $30.8 million (3 percent discount rate) for Options D or E. Estimated benefits for Option C are lower due to the reduction in the amount of marketable bottom ash relative to Options D and E (*i.e.*, BAT/PSES standards for bottom ash apply only to units with greater than 400 MW capacity), and benefits for Options A and B are lower yet, as they derive from the incremental marketability of fly ash only.

10.3 Implications of Revised Steam Electric Plant Loading Estimates

As described in *Section 1.4.3*, EPA revised its estimates of pollutant loadings in steam electric power plant discharges after completing the benefit analyses. Estimated benefits from the enhanced marketability of CCR do not depend on pollutant loadings to receiving waters and therefore the monetized benefit estimates provided in this Chapter are unaffected by revisions to steam electric plant loading estimates.

10.4 Limitations and Uncertainties

Key uncertainties and limitations include:

- Benefits from marketed CCR are sensitive to assumptions about CCR generation. The analysis assumes that the amount of CCR generated by steam electric power plants is constant throughout the analysis, *i.e.*, coal-fired plants generate a constant quantity of electricity. This is consistent with the screening-level cost and economic impact analysis framework (see RIA report). However, the

Department of Energy and EPA both project that generation from steam electric plants will decline over time, due to a variety of market factors, including environmental regulations. This decline would reduce the quantity of CCR generated, available to be marketed for beneficial use, and the associated benefits estimated in this memo. The Agency accounted for disposal costs in its economic impact analysis assuming that a constant quantity of CCR would need to be disposed of. Therefore, the assumption of constant CCR generation does not result in an overstatement of avoided disposal benefits since they offset costs already calculated elsewhere. In contrast, non-disposal related benefits could be lower when accounting for the reduction in CCR generation.

- As discussed above, EPA assumed that conversions to dry handling at plants already marketing wet ash in the baseline are not incremental economic benefits because there is no change in the total amount of CCR that is beneficially used. Relaxing this assumption could increase estimated cost offsets to the extent that these plants avoid certain compliance or operational costs that have been counted against the ELGs.
- Steam electric plants may not market all of their CCR within a given year; for example, they may instead temporarily store it. This affects both the time profile and value of beneficial reuse benefits. To the extent that steam electric plants may or may not be able to completely avoid the annual O&M costs of disposal, EPA's analysis is an upper bound.
- Certain other dimensions of this analysis may lead to under-estimated benefits of CCR re-use. For example, EPA assumed that facilities only offset O&M costs of disposal. To the extent that some plants are actually able to avoid or offset capital costs of compliance or other longer-term costs given reduced need for landfilling (*e.g.*, costs of securing and developing additional disposal sites), EPA's analysis is a lower-bound on the benefits of dry handling CCR.

11 Summary of Total Monetized Benefits

11.1 Total Annualized Benefits

Table 11-1 and *Table 11-2*, on the next two pages, summarize the total annual monetized benefits using 3 percent and 7 percent discount rates, respectively. *Table 11-3* and *Table 11-4* compile, for each of the five analyzed regulatory options, the time profiles of total (non-discounted) monetized benefits. The tables also report the calculated present and annualized values of benefits at 3 percent and 7 percent discount rates, respectively.

The estimated total monetized benefits of the five regulatory options EPA analyzed range from $41.1 million to $565.6 million per year using a 3 percent discount rate, depending on the option ($37.2 million to $478.4 million per year using a 7 percent discount rate), and whether the analysis includes air-related benefits. Option D has total benefits (including air-related benefits) of approximately $450.6 million to $565.6 million using a 3 percent discount rate and $387.3 million to $478.4 million using a 7 percent discount rate.

The monetized benefits of the final rule do not account for all benefits because they omit various sources of benefits to society from reduced steam electric pollutant discharges, such as reduction in certain non-cancer health risk (*e.g.*, effects of cadmium on kidney functions and bone density) and reduced cost of drinking water treatment. See *Chapter 2* for a discussion of categories of benefits EPA did not monetize.

Finally, EPA was able to estimate air-related benefits for Options B and D only (see *Chapter 7*). Benefits for options A, C and E are therefore understated to a greater degree than the other options; in particular, EPA expects that the benefits for Option E would be higher than those for Option D if air-related benefits were included. See *Section 13.1* for an extrapolation of potential air-related benefits for these options.

As described in *Section 1.4.3*, EPA revised its estimates of pollutant loadings in steam electric power plant discharges after completing the benefit analyses. These revisions are likely to reduce benefit estimates in the following four categories: human health, nonmarket water quality benefits, benefits to threatened and endangered species and avoided dredging costs. For several reasons — notably the fact that revisions do not affect all plants equally and the model functions are not linear — it would be inappropriate to simply scale the monetized benefits based on the aggregate changes in loadings. Therefore, EPA qualitatively assessed effects of pollutant loading reductions on the relevant benefit categories (see Chapters 3, 4, 5, and 9 for detail). The Agency concluded that although the revised loadings are likely to reduce the estimated benefit in four benefit categories, the magnitude of these reductions is likely to be small compared to the total benefits of the rule.

Chapters 3 through *10* provide more detail on limitation and uncertainty inherent in the analysis of each benefit category.

Table 11-1: Summary of Total Annualized Benefits at 3 Percent (Millions; 2013$)

Benefit Category	Option A			Option B			Option C			Option D			Option E		
	Low	Mid[f]	High	Low	Mid[f]	High	Low	Mid[f]	High	Low	Mid[f]	High	Low	Mid[f]	High
Human Health Benefits[g]	**$5.4**	**$5.7**	**$6.1**	**$5.4**	**$5.8**	**$6.1**	**$11.3**	**$11.8**	**$12.4**	**$16.5**	**$17.2**	**$17.9**	**$16.7**	**$17.5**	**$18.3**
Reduced IQ losses in children from exposure to lead[a,g]	$0.3	$0.4	$0.5	$0.3	$0.4	$0.5	$0.5	$0.6	$0.7	$0.8	$1.0	$1.1	$0.8	$1.0	$1.1
Reduced CVD in adults from exposure to lead[g]		$3.8			$3.8			$8.4			$12.8			$12.8	
Reduced IQ losses in children from exposure to mercury[a,g]	$1.3	$1.6	$1.8	$1.3	$1.6	$1.9	$2.4	$2.9	$3.4	$2.9	$3.5	$4.0	$3.1	$3.8	$4.4
Avoided cancer cases from exposure to arsenic[b,g]		<$0.1			<$0.1			<$0.1			<$0.1			<$0.1	
Improved Ecological Conditions and Recreational Uses[g]	**$4.2**	**$4.9**	**$23.4**	**$15.0**	**$18.9**	**$83.7**	**$19.6**	**$26.0**	**$109.4**	**$23.3**	**$31.3**	**$129.5**	**$25.1**	**$34.0**	**$140.0**
Use and nonuse values for water quality improvements[g]	$4.2	$4.9	$23.4	$15.0	$18.9	$83.7	$19.6	$26.0	$109.4	$23.2	$31.3	$129.5	$25.1	$34.0	$140.0
Nonuse values of T&E species[b,g]	<$0.1	<$0.1	<$0.1	<$0.1	<$0.1	<$0.1	<$0.1	<$0.1	<$0.1	<$0.1	<$0.1	<$0.1	<$0.1	<$0.1	<$0.1
Market and Productivity Benefits	**$31.5**	**$32.8**	**$34.2**	**$31.5**	**$32.8**	**$34.2**	**$107.2**	**$109.5**	**$111.9**	**$126.4**	**$130.0**	**$133.7**	**$126.4**	**$130.0**	**$133.7**
Avoided impoundment failures	$20.1	$21.5	$22.9	$20.1	$21.5	$22.9	$82.2	$84.5	$86.9	$95.6	$99.2	$102.9	$95.6	$99.2	$102.9
Reduced dredging costs[b]		<$0.1			<$0.1			<$0.1			<$0.1			< $0.1	
Ash marketing benefits		$11.3			$11.3			$25.0			$30.8			$30.8	
Air-related benefits		**NE**			**$110.2**			**NE**			**$284.5**			**NE**	
Reduced human health effects		NE			$57.8			NE			$144.7			NE	
Reduced CO_2 emissions[c]		NE			$52.5			NE			$139.8			NE	
Reduced water withdrawals[b]		**<$0.1**			**<$0.1**			**<$0.1**			**<$0.1**			**<$0.1**	

Table 11-1: Summary of Total Annualized Benefits at 3 Percent (Millions; 2013$)

Benefit Category	Option A			Option B			Option C			Option D			Option E		
	Low	Mid[f]	High	Low	Mid[f]	High	Low	Mid[f]	High	Low	Mid[f]	High	Low	Mid[f]	High
Total (excluding air-related Benefits)[d]	**$41.1**	**$43.4**	**$63.7**	**$51.9**	**$57.5**	**$124.0**	**$138.1**	**$147.4**	**$233.7**	**$166.1**	**$178.5**	**$281.2**	**$168.3**	**$181.6**	**$292.0**
Total (including air-related Benefits)[d,e]	**NE**	**NE**	**NE**	**$162.2**	**$167.8**	**$234.2**	**NE**	**NE**	**NE**	**$450.6**	**$463.0**	**$565.6**	**NE**	**NE**	**NE**

Source: U.S. EPA Analysis, 2015

"NE" indicates that EPA did not estimate the benefits. Air-related benefits of Option A are expected to be less than those for Option B; air-related benefits for Option C are expected to be between those of Options B and D; and air-related benefits of Option E are expected to be greater than those for Option D.

a. Value includes reduced IQ losses and avoided cost of compensatory education in children from exposure to lead. For details see *Chapter 3*.

b. "< $0.1" indicates that the monetized annual benefits are positive but less than $0.1 million.

c. For the valuation of benefits from reductions in CO_2 emissions EPA relied on the 3 percent average social cost of carbon estimate.

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

e. The total monetized benefits for options A, C, and E do not include air-related benefits. This category of benefits was analyzed for Options B and D only (see *Chapter 7*).

f. EPA estimated use and nonuse values for water quality improvements using two different meta-regression models of willingness-to-pay. One model provides the low and high bounds while a different model provides a central estimate (included in this table in the mid-range column). For this reason, the mid-range estimate differs from the midpoint of the range for this benefit category. For details, see *Chapter 4*.

g. Estimates for this benefit category do not reflect revised pollutant loadings, which could result in lower monetized benefits. See *Section 1.4.3* for details.

Table 11-2: Summary of Total Annualized Benefits at 7 Percent (Millions; 2013$)

Benefit Category	Option A			Option B			Option C			Option D			Option E		
	Low	Mid[f]	High	Low	Mid[f]	High	Low	Mid[f]	High	Low	Mid[f]	High	Low	Mid[f]	High
Human Health Benefits[g]	**$3.4**	**$3.5**	**$6.7**	**$3.4**	**$3.5**	**$14.2**	**$7.4**	**$7.6**	**$7.7**	**$11.3**	**$11.4**	**$11.6**	**$11.3**	**$11.5**	**$11.6**
Reduced IQ losses in children from exposure to lead[a,g]	$0.1	$0.1	$0.1	$0.1	$0.1	$0.1	$0.1	$0.1	$0.1	$0.1	$0.2	$0.2	$0.1	$0.2	$0.2
Reduced CVD in adults from exposure to lead[g]		$3.1			$3.1			$7.0			$10.7			$10.7	
Reduced IQ losses in children from exposure to mercury[a,g]	$0.2	$0.3	$3.5	$0.2	$0.3	$11.0	$0.4	$0.5	$0.6	$0.5	$0.6	$0.7	$0.5	$0.6	$0.8
Avoided cancer cases from exposure to arsenic[b,g]		<$0.1			<$0.1			<$0.1			<$0.1			<$0.1	
Improved Ecological Conditions and Recreational Uses[g]	**$3.3**	**$3.9**	**$18.6**	**$12.0**	**$15.2**	**$66.7**	**$15.7**	**$20.9**	**$87.4**	**$18.6**	**$25.1**	**$103.4**	**$20.1**	**$27.3**	**$111.7**
Use and nonuse values for water quality improvements[g]	$3.3	$3.9	$18.6	$12.0	$15.2	$66.7	$15.7	$20.9	$87.3	$18.5	$25.1	$103.4	$20.0	$27.3	$111.7
Nonuse values of T&E species[b,g]	<$0.1	<$0.1	<$0.1	<$0.1	< $0.1	<$0.1	<$0.1	< $0.1	<$0.1	<$0.1	< $0.1	<$0.1	<$0.1	< $0.1	<$0.1
Market and Productivity Benefits	**$30.4**	**$31.6**	**$32.7**	**$30.4**	**$31.6**	**$32.7**	**$92.5**	**$94.4**	**$96.4**	**$108.8**	**$111.8**	**$114.8**	**$108.8**	**$111.8**	**$83.7**
Avoided impoundment failures	$16.1	$17.3	$18.4	$16.1	$17.3	$18.4	$66.4	$68.3	$70.3	$77.7	$80.7	$83.7	$77.7	$80.7	$83.7
Reduced dredging costs[b]		< $0.1			< $0.1			< $0.1			< $0.1			< $0.1	
Ash marketing benefits		$14.3			$14.3			$26.1			$31.1			$31.1	
Air-Related Benefits		**NE**			**$103.6**			**NE**			**$248.6**			**NE**	
Reduced human health effects		NE			$51.1			NE			$108.8			NE	
Reduced CO_2 emissions[c]		NE			$52.5			NE			$139.8			NE	
Reduced water withdrawals[b]		**<$0.1**			**<$0.1**			**<$0.1**			**<$0.1**			**<$0.1**	

Table 11-2: Summary of Total Annualized Benefits at 7 Percent (Millions; 2013$)

Benefit Category	Option A			Option B			Option C			Option D			Option E		
	Low	Mid[f]	High	Low	Mid[f]	High	Low	Mid[f]	High	Low	Mid[f]	High	Low	Mid[f]	High
Total (excluding air-related Benefits)[d]	**$37.2**	**$38.9**	**$58.0**	**$45.8**	**$50.2**	**$113.7**	**$115.6**	**$122.9**	**$191.4**	**$138.7**	**$148.4**	**$229.8**	**$140.2**	**$150.6**	**$207.1**
Total (including air-related Benefits)[d,e]	**NE**	**NE**	**NE**	**$149.4**	**$153.8**	**$217.3**	**NE**	**NE**	**NE**	**$387.3**	**$397.0**	**$478.4**	**NE**	**NE**	**NE**

Source: U.S. EPA Analysis, 2015

"NE" indicates that EPA did not estimate the benefits. Air-related benefits of Option A are expected to be less than those for Option B; air-related benefits for Option C are expected to be between those of Options B and D; and air-related benefits of Option E are expected to be greater than those for Option D.

a. Value includes reduced IQ losses and avoided cost of compensatory education in children from exposure to lead. For details see *Chapter 3*.

b. "< $0.1" indicates that the monetized annual benefits are positive but less than $0.1 million.

c. For the valuation of benefits from reductions in CO_2 emissions EPA relied on the 3 percent average social cost of carbon estimate.

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

e. The total monetized benefits for options A, C, and E do not include air-related benefits. This category of benefits was analyzed for Options B and D only (see *Chapter 7*).

f. EPA estimated use and nonuse values for water quality improvements using two different meta-regression models of willingness-to-pay. One model provides the low and high bounds while a different model provides a central estimate (included in this table in the mid-range column). For this reason, the mid-range estimate differs from the midpoint of the range for this benefit category. For details, see *Chapter 4*.

g. Estimates for this benefit category do not reflect revised pollutant loadings, which could result in lower monetized benefits. See *Section 1.4.3* for details.

11.2 Time Profile of Benefits

Table 11-3 and *Table 11-4* compile the time profiles of total (non-discounted) monetized benefits including air-related benefits for Options B and D, and the calculated annualized values of benefits at 3 percent and 7 percent discount rates, respectively. The time profile is based on mid-range (or central) estimates for benefits for which benefits are presented as a range in *Table 11-1* and *Table 11-2*.

As shown in the tables, benefits under Option D increase from 2019 until 2022, then decline in 2023 before gradually increasing. This 2023 decline is due to an IPM-projected increase in SO_2 relative to baseline (negative benefits). For Option B, there is a similar decline in 2023 as well as a larger decline in benefits in 2028. As with Option D, these declines are attributable to IPM-projected increases in SO_2 (negative benefits), but also occur due to smaller estimated CO_2 and NO_x reductions when compared to earlier years. For both Options B and D (excluding the increases in SO_2 in the given periods), IPM indicates a decline in net air emissions reductions between 2019 and 2033 followed by an increase in net reductions in 2034. For more details on the IPM projections, see *Chapter 7*.

Table 11-3: Time Profile of Benefits at 3 Percent (Millions; 2013$) (Including Air-Related Benefits for Options B and D)

Year	Option A[a]	Option B	Option C[a]	Option D	Option E[a]
2015	$0.0	$0.0	$0.0	$0.0	$0.0
2016	$0.0	$0.0	$0.0	$0.0	$0.0
2017	$0.0	$0.0	$0.0	$0.0	$0.0
2018	$0.0	$0.0	$0.0	$0.0	$0.0
2019	$3.8	$291.4	$16.4	$544.8	$30.3
2020	$5.5	$296.6	$39.9	$578.7	$58.7
2021	$18.7	$327.6	$83.3	$633.5	$115.1
2022	$31.0	$344.4	$155.8	$718.1	$193.2
2023	$57.2	$176.1	$189.9	$310.5	$232.6
2024	$58.0	$179.1	$191.6	$314.9	$235.1
2025	$58.4	$181.5	$192.3	$317.6	$235.9
2026	$58.6	$184.0	$192.6	$319.9	$236.2
2027	$58.7	$186.3	$192.7	$321.8	$236.2
2028	$58.7	$31.1	$192.7	$422.6	$236.0
2029	$58.6	$30.4	$192.5	$423.2	$235.5
2030	$58.5	$29.9	$192.3	$426.2	$235.1
2031	$58.6	$29.6	$192.3	$428.8	$234.8
2032	$58.6	$29.2	$192.2	$431.6	$234.4
2033	$58.6	$28.8	$192.1	$434.4	$234.1
2034	$58.6	$224.3	$192.1	$670.1	$233.8
2035	$58.7	$226.7	$192.1	$676.4	$233.6
2036	$58.7	$229.2	$192.1	$682.7	$233.5
2037	$58.8	$231.7	$192.2	$689.1	$233.4
2038	$58.9	$234.2	$192.4	$695.6	$233.4
2039	$59.0	$236.8	$192.5	$702.1	$233.4
2040	$59.2	$239.3	$192.7	$708.6	$233.5
2041	$59.3	$241.9	$192.9	$715.3	$233.7
2042	$59.3	$243.2	$193.1	$718.6	$233.8
Annualized Benefits, 3%[b]	**$43.4**	**$167.8**	**$147.4**	**$463.0**	**$181.6**

Source: U.S. EPA Analysis, 2015

a. Estimates for Options A, C and E do not include air-related benefits. This category of benefits was only estimated for Options B and D (see *Chapter 7*).

b. Total annualized year-specific benefits may not sum to the total annualized benefits due to rounding.

Table 11-4: Time Profile of Benefits at 7 Percent (Millions; 2013$) (Including Air-Related Benefits for Options B and D)

Year	Option A[a]	Option B	Option C[a]	Option D	Option E[a]
2015	$0.0	$0.0	$0.0	$0.0	$0.0
2016	$0.0	$0.0	$0.0	$0.0	$0.0
2017	$0.0	$0.0	$0.0	$0.0	$0.0
2018	$0.0	$0.0	$0.0	$0.0	$0.0
2019	$3.8	$270.0	$16.4	$512.5	$30.3
2020	$5.5	$275.5	$39.9	$547.5	$58.7
2021	$16.9	$304.5	$80.1	$597.4	$110.8
2022	$29.2	$321.3	$152.5	$682.1	$188.8
2023	$55.4	$170.3	$186.6	$309.7	$228.2
2024	$56.2	$173.3	$188.3	$314.0	$230.6
2025	$56.5	$175.7	$188.9	$316.4	$231.4
2026	$56.7	$178.2	$189.2	$318.8	$231.6
2027	$56.8	$180.4	$189.3	$320.7	$231.6
2028	$56.8	$34.2	$189.3	$409.6	$231.3
2029	$56.6	$33.5	$189.1	$410.2	$230.8
2030	$56.5	$33.0	$188.9	$413.0	$230.4
2031	$56.6	$32.7	$188.8	$415.6	$230.0
2032	$56.6	$32.3	$188.6	$418.3	$229.6
2033	$56.6	$31.9	$188.5	$421.1	$229.2
2034	$56.6	$214.9	$188.5	$641.9	$228.9
2035	$56.6	$217.3	$188.5	$648.1	$228.7
2036	$56.7	$219.8	$188.5	$654.4	$228.5
2037	$56.8	$222.3	$188.5	$660.7	$228.4
2038	$56.8	$224.8	$188.6	$667.1	$228.4
2039	$56.9	$227.3	$188.8	$673.5	$228.3
2040	$57.0	$229.8	$188.9	$680.0	$228.4
2041	$57.2	$232.4	$189.1	$686.6	$228.5
2042	$57.2	$233.7	$189.2	$689.8	$228.5
Annualized Benefits, 7%[b]	**$38.9**	**$153.8**	**$122.9**	**$397.0**	**$150.6**

Source: U.S. EPA Analysis, 2015

a. Estimates for Options A, C and E do not include air-related benefits. This category of benefits was only estimated for Options B and D (see *Chapter 7*).

b. Total annualized year-specific benefits may not sum to the total annualized benefits due to rounding. Additionally, note that SCC values are annualized at 3 percent, whereas other benefits are annualized at 7 percent.

12 Summary of Total Costs

This chapter develops EPA's estimates of the costs to society resulting from the final ELGs. As analyzed in this chapter, the *costs* of regulatory actions are the *opportunity costs* to society of employing resources to prevent the environmental damage otherwise occurring from discharges of wastewater containing metals, nutrients, and other pollutants.

12.1 Overview of Costs Analysis Framework

RIA Chapter 3: Compliance Costs presents EPA's development of costs to the 1,080 steam electric power plants subject to the final ELGs (U.S. EPA, 2015c). These costs are used as the basis of the social cost analysis. However, the compliance costs used to estimate total costs differ in their consideration of taxes from those reported in *RIA Chapter 3*, which were calculated for the purpose of estimating the private costs and the economic impacts of the ELGs. In the analysis of costs to society, compliance costs are considered without accounting for any tax effects. The costs to society are the full value of the resources used, whether they are paid for by the regulated plants, by taxpayers in the form of lost tax revenues, or by some combination.[74]

As described in *Chapter 1*, EPA assumed that steam electric power plants, *in the aggregate*, would implement control technologies during a 5-year period from 2019 to 2023. For this analysis, EPA developed a year-explicit schedule of compliance outlays over the period of 2019 through 2042.[75] 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.

After compliance costs were assigned to the year of occurrence, the Agency adjusted these costs for real change between their stated year 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.

Note that the CCI and ECI adjustment factors were developed only through the year 2022; after these years, EPA assumed that the real change in prices is zero – that is, costs are expected to change in line with general inflation. EPA judges this to be a reasonable assumption, given 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 promulgation year by discounting the cost in each year back to 2015, 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

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[74] For the impact analyses, compliance costs are measured as they affect the financial performance of the regulated plants and firms. The economic impact analyses therefore consider the tax deductibility of compliance expenditures, as appropriate depending on the tax status of the complying entity.

[75] The end of the analysis period, 2042, was determined based on the life of the longest-lived compliance technology implemented at any steam electric power plant (20 years), and the last year of technology implementation (2023).

(U.S. 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 24-year social cost analysis period. EPA assumed no re-installation of compliance technology during the period covered by the social cost analysis.

To assess the economic costs of the ELGs 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 ELGs. In this analysis, EPA assumed that 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. Finally, EPA assumed in its social cost analysis that the final rule does not affect the aggregate quantity of electricity that would be sold to consumers and, thus, that the rule's social cost would include no loss in consumer and producer surplus *from lost electricity sales* by the electricity industry in aggregate. Given the small impact of the final rule on electricity production cost for the total industry, EPA believes that this assumption is reasonable for the social cost analysis (for more details on the impacts of the final rule on electricity production cost, see *RIA Chapter 5: Electricity Market Analyses*).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 promulgation and technology implementation years.[76]

Finally, as discussed in *RIA Chapter 10 (Section 10.7: Paperwork Reduction Act of 1995)*, the final ELGs are not expected to result in additional administrative costs for plants to implement, and state and federal NPDES permitting authorities to administer, the final ELGs. 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 ELGs.

12.2 **Key Findings for Regulatory Options**

Table 12-1 presents annualized costs for each of the five regulatory options. At a 3 percent discount rate, estimated annualized costs range between $120.5 million under Option A and $536.0 million under Option E. The final BAT/PSES options for existing sources (Option D) have annualized costs of $479.5 million at a 3 percent discount rate, and $471.2 million at a 7 percent discount rate.[77]

Table 12-1: Summary of Annualized Costs (Millions; $2013)

Regulatory Option	3% Discount Rate	7% Discount Rate
Option A	$120.5	$116.9
Option B	$198.7	$194.7
Option C	$383.5	$379.9
Option D	$479.5	$471.2
Option E	$536.0	$525.8

Source: U.S. EPA Analysis, 2015.

Table 12-2 provides additional detail on the social cost calculations. The table compiles, for each of the five regulatory options EPA analyzed for the final ELG, the time profiles of compliance costs incurred. The table

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

[77] Similarities in the values obtained when discounting costs using 3 percent and 7 percent are due to the time profile of the costs, specifically the timing and relative magnitude of upfront capital costs versus ongoing O&M expenditures.

also reports the calculated annualized values of costs at 3 percent and 7 percent discount rates.[78] The maximum compliance outlays are incurred over the years 2019 through 2023, *i.e.*, during the estimated window when steam electric power plants are expected to implement compliance technologies.

Table 12-2: Time Profile of Costs to Society (Millions; $2013)

Year	Option A	Option B	Option C	Option D	Option E
2015	$0.0	$0.0	$0.0	$0.0	$0.0
2016	$0.0	$0.0	$0.0	$0.0	$0.0
2017	$0.0	$0.0	$0.0	$0.0	$0.0
2018	$0.0	$0.0	$0.0	$0.0	$0.0
2019	$388.8	$641.8	$1,143.4	$1,336.6	$1,427.1
2020	$132.3	$276.7	$631.1	$856.7	$950.3
2021	$390.2	$620.2	$1,243.4	$1,364.9	$1,498.0
2022	$201.7	$374.2	$882.5	$1,123.1	$1,331.8
2023	$286.6	$512.9	$1,058.8	$1,332.7	$1,497.4
2024	$75.7	$120.2	$215.3	$282.3	$317.9
2025	$83.0	$127.5	$222.9	$291.2	$327.5
2026	$78.3	$122.7	$219.0	$289.5	$326.0
2027	$80.9	$125.4	$219.9	$289.1	$325.9
2028	$79.0	$123.4	$218.6	$286.6	$324.1
2029	$84.9	$129.3	$230.9	$304.2	$341.2
2030	$83.2	$127.7	$227.1	$298.6	$334.2
2031	$85.4	$129.8	$232.1	$303.7	$340.0
2032	$84.6	$129.0	$229.5	$303.4	$340.0
2033	$85.1	$129.5	$230.7	$302.9	$339.7
2034	$77.8	$122.2	$218.0	$286.8	$324.2
2035	$83.1	$127.5	$223.8	$293.4	$330.5
2036	$79.0	$123.5	$221.5	$290.7	$326.3
2037	$82.6	$127.1	$224.0	$295.7	$332.0
2038	$81.4	$125.8	$224.0	$295.2	$331.5
2039	$84.4	$128.8	$229.4	$300.3	$336.7
2040	$83.9	$128.3	$226.5	$298.0	$334.5
2041	$83.8	$128.2	$226.9	$297.2	$333.2
2042	$83.3	$127.7	$224.9	$293.9	$329.5
Annualized Costs, 3%	**$120.5**	**$198.7**	**$383.5**	**$479.5**	**$536.0**
Annualized Costs, 7%	**$116.9**	**$194.7**	**$379.9**	**$471.2**	**$525.8**

Source: U.S. EPA Analysis, 2015.

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[78] Whereas EPA calculated the time profile of benefits using discount rate-specific social cost of carbon estimates and therefore obtained time profiles that are specific to the discount rates (see Table 11-3 and Table 11-4), the time profile of costs does not depend on the discount rate.

13 Benefits and Costs

This chapter compares total monetized benefits and costs for the five regulatory options analyzed for the final ELGs. Benefits and costs are compared on two bases: (1) for each of the options analyzed 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: Other Administrative Requirements* of the RIA; U.S. EPA, 2015c).

13.1 Comparison of Benefits and Costs by Option

Chapter 11 and *Chapter 12* present estimates of the benefits and costs, respectively, for the regulatory options evaluated in developing the final ELGs.

Table 13-1 presents EPA's estimates of benefits and costs of the regulatory options for existing steam electric power plants, at 3 percent and 7 percent discount rates, and annualized over 24 years. These values are all in 2013 dollars and are based on the discounting of costs and benefits to 2015, the rule promulgation year.

As discussed in *Chapter 11*, EPA did not analyze air-related benefits for Options A, C, and E. The total monetized benefits for those options are therefore understated. To compare the costs and benefits of these options, EPA calculated the average ratio of total benefits *with* air-related benefits to total benefits *without* air-related benefits for Options B and D,[79] then applied the average ratio to Options A, C, and E to extrapolate total monetized benefits including air-related benefits for these options. These extrapolated, approximate benefits are shown in *Table 13-1*.

Table 13-1: Total Annualized Benefits and Costs by Regulatory Option and Discount Rate (Millions; 2013$)

Regulatory Option	Total Monetized Benefits			Total Monetized Benefits, Including Extrapolated Values[a]			Total Costs
	Low	Mid[b]	High	Low	Mid[b]	High	
3% Discount Rate							
Option A	$41.1	$43.4	$63.7	$122.1	$122.2	$125.7	$120.5
Option B	$162.2	$167.8	$234.2	$162.2	$167.8	$234.2	$198.7
Option C	$138.1	$147.4	$233.7	$410.4	$414.5	$461.3	$383.5
Option D	$450.6	$463.0	$565.6	$450.6	$463.0	$565.6	$479.5
Option E	$168.3	$181.6	$292.0	$500.2	$510.8	$576.3	$536.0

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[79] This ratio averaged 2.97 for low benefits, 2.81 for mid-range, and 1.97 for high.

Table 13-1: Total Annualized Benefits and Costs by Regulatory Option and Discount Rate (Millions; 2013$)

Regulatory Option	Total Monetized Benefits			Total Monetized Benefits, Including Extrapolated Values[a]			Total Costs
	Low	Mid[b]	High	Low	Mid[b]	High	
7% Discount Rate							
Option A	$37.2	$38.9	$58.0	$110.5	$109.5	$114.4	$116.9
Option B	$149.4	$153.8	$217.3	$149.4	$153.8	$217.3	$194.7
Option C	$115.6	$122.9	$191.4	$343.7	$345.6	$377.8	$379.9
Option D	$387.3	$397.0	$478.4	$387.3	$397.0	$478.4	$471.2
Option E	$140.2	$150.6	$207.1	$416.8	$423.7	$408.7	$525.8

Source: U.S. EPA Analysis, 2015.

a. EPA did not analyze air-related benefits for Options A, C, and E. This category of benefits was only estimated for Options B and D (see *Chapter 7*). EPA adjusted the total benefits estimated for Options A, C and E by multiplying the totals without air-related benefits by the average ratio of [total with air-related benefits]/[total without air-related benefits] for Options B and D.

b. EPA estimated use and nonuse values for water quality improvements using two different meta-regression models of WTP. One model provides the low and high bounds while a different model provides a central estimate (included in this table under the mid-range column). For this reason, the mid benefit estimate differs from the midpoint of the benefits range. For details, see *Chapter 4*.

13.2 Analysis of Incremental Benefits and Costs

In addition to comparing benefits and costs for each regulatory option, as presented in the preceding section, EPA also analyzed 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 by itself: for a given option, which is greater – costs or benefits – and by how much? In contrast, incremental analysis looks at the differential relationship of benefits and costs across options and poses a different question: as increasingly more costly options are considered, by what amount do benefits, costs, and net benefits (*i.e.*, benefits minus costs) change from option to option? Incremental net benefit analysis provides insight into the net gain to society from imposing increasingly more costly requirements.

EPA conducted the incremental net benefit analysis by calculating, for the five regulatory options, the change in net benefits, from option to option, in moving from the least stringent option to successively more stringent options. As described in *Chapter 1*, the regulatory options differ in the technology basis used to determine effluent limits and standards 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, and the distribution and characteristics of steam electric power plants that would implement the technologies and of the receiving waterbodies.

As noted previously, however, the total monetized benefits for Options A, C, and E do not include air-related benefits; this benefit category is included in results for Options B and D only. Therefore, to allow for consistent calculation of incremental benefits as one moves from one option to the next, EPA used the extrapolated total benefits estimated for Options A, C, and D to include the air-related benefits for these options (see *Table 13-1)*.

As reported in *Table 13-2*, EPA estimates that the annual monetized costs exceed the mid-range annual monetized benefits for the final ELG by $16.5 million using a 3 percent discount rate and $74.2 million using a 7 percent discount rate.

Using a 3 percent discount rate, the incremental net annual monetized benefits moving from Option A to Option B is -$33 million (the negative value indicates that the increase in costs is larger than the increase in benefits). Moving from Option B to Option C, the change is $62 million, with the positive value indicating that the increase in benefits is larger than the increase in costs. Moving from Option C to Option D, and from Option D to Option E, the change is negative, at -$48 million and -$9 million, respectively.

Table 13-2: Incremental Net Benefit Analysis (Millions; 2013$)

Regulatory Option[a]	**Total Annual Monetized Benefits, Including Adjusted or Inferred Values**			**Total Social Costs**	**Net Annual Monetized Benefits[a]**			**Incremental Net Annual Monetized Benefits[b]**		
	Low	**Mid[d]**	**High**		**Low**	**Mid[d]**	**High**	**Low**	**Mid[d]**	**High**
3% Discount Rate										
Option A	$122.1	$122.2	$125.7	$120.5	$1.6	$1.6	$5.2	-	-	-
Option B	$162.2	$167.8	$234.2	$198.7	-$36.5	-$30.9	$35.6	-$38.1	-$32.6	$30.4
Option C	$410.4	$414.5	$461.3	$383.5	$26.9	$31.0	$77.8	$63.4	$61.9	$42.2
Option D	$450.6	$463.0	$565.6	$479.5	-$28.9	-$16.5	$86.1	-$55.8	-$47.5	$8.3
Option E	$500.2	$510.8	$576.3	$536.0	-$35.8	-$25.2	$40.3	-$6.8	-$8.7	-$45.8
7% Discount Rate										
Option A	$110.5	$109.5	$114.4	$116.9	-$6.4	-$7.4	-$2.5	-	-	-
Option B	$149.4	$153.8	$217.3	$194.7	-$45.3	-$40.9	$22.5	-$38.9	-$33.5	$25.0
Option C	$343.7	$345.6	$377.8	$379.9	-$36.2	-$34.3	-$2.1	$9.1	$6.6	-$24.6
Option D	$387.3	$397.0	$478.4	$471.2	-$83.9	-$74.2	$7.2	-$47.7	-$39.9	$9.2
Option E	$416.8	$423.7	$408.7	$525.8	-$109.0	-$102.1	-$117.1	-$25.1	-$27.9	-$124.3

Source: U.S. EPA Analysis, 2015.

a. EPA did not analyze air-related benefits for Options A, C, and E. This category of benefits was only estimated for Options B and D (see *Chapter 7*). EPA adjusted the total benefits estimated for Options A, C, and E by multiplying the totals without air-related benefits by the average ratio of [total with air-related benefits]/[total without air-related benefits] for Options B and D.

b. Net benefits are calculated by subtracting total annualized costs from total annual monetized benefits.

c. Incremental net benefits are equal to the difference between net benefits of an option and net benefits of the previous, less stringent option.

d. EPA estimated use and nonuse values for water quality improvements using two different meta-regression models of WTP. One model provides the low and high bounds while a different model provides a central estimate (included in this table under the mid-range column). For this reason, the mid benefit estimate differs from the midpoint of the benefits range. For details, see *Chapter 4*.

14 Environmental Justice

Executive Order (E.O.) 12898 (59 FR 7629, February 11, 1994) requires that, to the greatest extent practicable and permitted by law, each Federal agency must make the achievement of environmental justice (EJ) part of its mission. E.O. 12898 provides that each Federal agency must conduct its programs, policies, and activities that substantially affect human health or the environment in a manner that ensures such programs, policies, and activities do not have the effect of (1) excluding persons (including populations) from participation in, or (2) denying persons (including populations) the benefits of, or (3) subjecting persons (including populations) to discrimination under such programs, policies, and activities because of their race, color, or national origin.

To meet the objectives of E.O. 12898, EPA examined whether the benefits from the final ELGs may be differentially distributed among population subgroups in the affected areas. EPA considered the following factors in this analysis: population characteristics, proximity to affected waters, exposure pathways, cumulative risk exposure, and susceptibility to environmental risk. For example, subsistence fishers rely on self-caught fish for a larger share of their food intake than do recreational fishermen, and as such may incur a larger share of benefits arising from the final ELGs.

As described in the following sections, EPA conducted two types of analyses to evaluate the EJ implications of the final ELGs: (1) summarizing the demographic characteristics of the households living in proximity to reaches that receive steam electric power plant discharges; and (2) analyzing the human health impacts from consuming self-caught fish on minority and/or low-income populations located within 50 miles of reaches affected by steam electric power plant discharges.[80] This second analysis seeks to provide more specific insight on the distribution of adverse health effects and benefits and to assess whether minority and/or low-income populations incur disproportionally high environmental impacts and/or are disproportionally excluded from realizing the benefits of this final rule.

The following two sections describe (1) a comparison of the socio-economic characteristics of the populations that live in proximity to steam electric power plants to state and national averages, and (2) the evaluation of human health effects and benefits that accrue to populations in different socio-economic cohorts.

14.1 Socio-economic Characteristics of Populations Residing in Proximity to Steam Electric Power Plants

For the first analysis, EPA assessed the demographic characteristics of the populations within specified distances of reaches that receive steam electric power plant discharges. The receiving reaches are those to which plants discharge directly in the baseline; for this first analysis, EPA did not include additional reaches located downstream from the receiving reaches (see BCA for a discussion of receiving and downstream reaches, U.S. EPA 2015a). The analysis is similar to the profile EPA had developed to support the proposed ELG, but looks at populations living within different, closer distances of steam electric power plants. The change was made in part to addresses comments EPA received on the need to look at communities in closer proximity to the plants, instead of the 100-mile buffer the Agency had used at proposal (see comment response document; U.S. EPA 2015d).[81]

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[80] As detailed in the *Chapter 3*, EPA used a distance of 50 miles to determine the affected population.

[81] Commenters recommended that EPA consider the characteristics of populations within 4 miles, 5 miles, 15 miles and 30 miles of the plants (see U.S. EPA, 2015d).

EPA collected population-specific Census data on:

- the percent of the population below the poverty threshold,[82] and
- the population categorized in various racial/ethnic groups, from which EPA calculated the percent of the population that belongs to a minority racial/ethnic group.[83]

EPA compiled these data for CBGs located within specified distances (*e.g.*, 1 mile, 3 miles, 15 miles, 30 miles, and 50 miles) of the reaches receiving steam electric power plant discharges. EPA compared demographic metrics to state and national averages to identify communities where EJ concerns may exist. EJ concerns may exist in areas where the percent of the population below the poverty threshold is higher than the state or national average or the percent of the population that is minority is above the state or national average.

This first analysis considers the spatial distribution of low-income and minority groups to determine whether these groups are more or less represented in the populations in proximity to reaches receiving steam electric power plant discharges. The specified distance buffers from the reaches are denoted below as the "benefit region." Populations within the benefit regions may be affected by steam electric power plant discharges and other environmental impacts in the baseline, and would be expected to benefit from environmental improvements resulting from the final ELGs. If the population within a benefit region has a larger proportion of minority or low-income families than the state average, it may indicate that the final ELGs may benefit communities that have been historically exposed to a disproportionate share of environmental impacts and thus contribute to redressing existing EJ concerns.

EPA used the U.S. Census Bureau's American Community Survey (ACS) data for 2006 to 2010 to identify poverty status (Table C17002) at the state and CBG levels. EPA also used 2010 U.S. Census data (Summary File 1; Table 8 – P3) to identify the percent of the population that is minority at the CBG and state levels. EPA overlaid the data with GIS data of buffer zones of specified distances from receiving reaches to characterize the affected communities living in proximity to the reaches. *Table 14-1* summarizes the socio-economic characteristics of benefit regions defined using radial distances of 1, 3, 10, 15, 30 and 50 miles from the receiving reaches.

Table 14-1: Socio-economic Characteristics of Communities Living in Proximity to Receiving Reaches

Distance from receiving reach	Total population (millions)	Percent minority	Percent below poverty level
1 mile	0.2	20.7%	16.4%
3 miles	1.1	23.4%	15.3%
15 miles	14.0	29.8%	13.6%
30 miles	37.4	31.5%	13.1%
50 miles	57.3	29.9%	13.1%
United States	**306.3**	**36.0%**	**13.9%**

Source: U.S. EPA analysis, 2015

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[82] 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.

[83] The racial/ethnic categories are based on available fish consumption data as well as the breakout of ethnic/racial populations in Census data, which distinguishes racial groups within Hispanic and non-Hispanic categories. Minority groups include: African American (non-Hispanic); Asian/Pacific Islander (non-Hispanic); Tribal/Native Alaskan (non-Hispanic); Other non-Hispanic; Mexican Hispanic, and Other Hispanic.

As shown in *Table 14-1*, approximately 200,000 people live within 1 mile of steam electric power plants currently discharging to surface waters, over 1.1 million live within 3 miles, and nearly 37.4 million people live within 30 miles. The statistics also show that a greater fraction of the communities living in close proximity to steam electric power plants is poor, when compared to the national average. Approximately 16.4 percent of households in communities within 1 mile of steam electric power plants have income below the poverty level as compared to a national average of 13.9 percent. A smaller fraction of the population within 1 mile of the plants belongs to minority racial or ethnic groups (20.7 percent), than the national average (36.0 percent). As one moves further away from the steam electric power plants, the fraction of the community that is below the poverty threshold goes down while the percent minority increases, so that the overall composition of the communities approaches that of the U.S. population overall. Thus, looking at communities within 30 miles of steam electric power plants, 13.1 percent of the population is below the poverty level (vs. 13.9 percent nationally) while 31.5 percent belong to a minority group (vs. 36.0 percent nationally).

The simple comparison to the national average masks important differences, however, between states, particularly given the non-uniform geographical distribution of plants across the country. EPA therefore also compared the demographic profile of affected communities to that of the state where they are located. *Table 14-2* summarizes the results of this comparison. Of the 37 states with communities within 1 mile of steam electric power plants, 11 states have communities with a higher percentage of households below the poverty threshold than the overall state, 17 have a higher percent of the population that is minority, and 10 have a higher proportion of poor *and* minority households. These results show the potential for localized differences indicative of potential EJ concern, but the overall comparison reveals no *systematic* difference in demographic characteristics of the populations living in proximity to the steam electric power plants that would indicate that any communities with EJ concern would be precluded from the benefits of the final ELGs.

Table 14-2: Socio-economic Characteristics of Affected Communities, Compared to State Average

Distance from receiving reach	Number of States with Affected Communities[a]	Number of States where Affected Communities… are Poorer … than the State Average	… have a Higher Proportion of Minority Population … than the State Average	… are Poorer and have a Higher Proportion of Minority Population … than the State Average
1 mile	37	11	17	10
3 miles	37	10	17	7
15 miles	38	21	16	19
30 miles	42	22	16	21
50 miles	45	19	9	12

Source: U.S. EPA analysis, 2015

a. "Affected communities" are Census Block Groups within the specified distance of one or more receiving reaches.

14.2 Distribution of Human Health Impacts and Benefits

The second type of analysis looks at the distribution of environmental effects and benefits to further inform understanding of the potential EJ concerns and the extent to which the final rule may mitigate them.

A significant share of the benefits of the final ELGs comes from reducing discharges of harmful pollutants to surface waters and associated reductions in fish tissue contamination. EPA quantified the human health benefits resulting from reducing exposure to pollutants in fish tissue in individuals who consume fish caught in reaches immediately receiving or downstream from steam electric plant discharges. The analysis relied on CBG- level data to estimate the number and characteristics of individuals exposed to steam electric pollutants through the consumption of self-caught fish, and race and ethnicity-specific assumptions to estimate exposure. This analysis allows the agency to report the distribution of benefits across population subgroups, including subgroups who may have been historically exposed to a disproportionate share of environmental impacts.

This section presents results for the two types of anglers analyzed: recreational anglers and subsistence fishers. *Chapter 3* provides more details on the approach used to identify the affected population, derive exposure, quantify health effects and monetize benefits.

EPA limited its analysis of the distribution of health effects and benefits to two pollutants (lead and mercury) due to the small benefits resulting from reducing arsenic discharges. Further, for recreational anglers, EPA focused on benefits accruing to infants and children due to the complexity of carrying the detailed socio-economic data through the models used to quantify the changes in premature mortality from cardiovascular disease (CVD) in adults. The outputs from the CVD benefit analyses do not provide sufficient information to assess changes across socio-economic subgroups. However, EPA did account for changes in the incidence of CVD attributable to the final ELGs when comparing recreational and subsistence fishers (see *Section 14.4*).

14.3 Distribution of Benefits across Benefitting Populations

Table 14-3 summarizes the estimated number of individuals exposed to steam electric pollutants through consumption of self-caught fish in the general population and in population subgroups that may be indicative of EJ concerns. As shown in the table, of the approximately 36.0 million people exposed to steam electric pollutants, 13.9 percent are poor, 34.4 percent are minority, and 6.5 percent are both poor and minority. Overall, 41.9 percent of potentially exposed individuals are categorized in at least one or more EJ subgroup based on their poverty level or race/ethnicity, while 58.1 percent are neither minority nor poor.

Table 14-3: Characteristics of Population Potentially Exposed to Steam Electric Pollutants via Consumption of Self-caught Fish

Subgroup	Minority		Non-Minority		Total	
Poor	2,345,972	6.5%	2,668,083	7.4%	5,014,055	13.9%
Non-Poor	10,042,390	27.9%	20,915,560	58.1%	30,957,950	86.1%
Total	12,388,362	34.4%	23,583,643	65.6%	35,972,005	100%

Source: U.S. EPA Analysis, 2015

The distribution of adverse health effects is a function of the characteristics of the affected population (*Table 14-3*), including age and sex,[84] ethnicity-specific exposure factors,[85] and reach water quality. *Table 14-4*

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[84] Some adverse health effects are analyzed only for individuals in certain age groups. For example, IQ point decrements from exposure to lead are calculated for children 0 to 7 years old and the baseline exposure therefore depends on the number of children within this age group in the affected population in each socio-economic subgroup. IQ point decrements from exposure to mercury are calculated for infants born within the analysis period and baseline exposure depends on the number of women of childbearing age (and fertility rates) in the affected population.

[85] Ethnicity-specific factors that determine exposure to pollutants in fish tissue include the assumed fish consumption rates and average fertility rate. For example, as described in Chapter 2 of the BCA, Asian/Pacific

shows the distribution of selected adverse health effects in the baseline. *Table 14-5* shows the distribution of adverse health effects avoided under each of the five options EPA analyzed in developing the final ELGs. Note that benefits follow the same distribution as avoided adverse health effects since each case is valued equally, irrespective of the socio-economic subgroup.

The two tables show results for three selected subgroups:

- Poor and minority (6.5 percent of the exposed population),
- Poor or minority (*i.e.*, but not both; 35.3 percent of the exposed population), and
- All others (*i.e.*, non-poor white; 58.1 percent of the exposed population).

The first two subgroups are the primary interest of this analysis as potentially indicative of EJ concerns.

Table 14-4: Distribution of Baseline IQ Point Decrements by Pollutant (2021 to 2042)

Pollutant	Poor & Minority (6.5% of Population)		Poor or Minority (35.3% of Population)		All Others (58.1% of Population)		Total	
Lead	6,266,344	8.0%	29,663,242	38.0%	42,214,217	54.0%	78,143,802	100%
Mercury	91,838	9.3%	439,403	44.6%	454,081	46.1%	985,322	100%

Source: U.S. EPA Analysis, 2015

Table 14-5: Distribution of Avoided IQ Point Decrements Relative to the Baseline, by Pollutant (2021 to 2042)

Pollutant and Exposed Population	Regulatory Option	Poor & Minority (6.5% of Population)		Poor or Minority (35.3% of Population)		All Others (58.1% of Population)		Total	
Children Exposed to Lead	Option A	78	9.2%	313	36.6%	462	54.2%	853	100%
	Option B	78	9.2%	313	36.6%	462	54.2%	853	100%
	Option C	128	9.9%	518	40.3%	640	49.8%	1,285	100%
	Option D	155	7.8%	693	34.9%	1,137	57.3%	1,985	100%
	Option E	155	7.8%	693	34.9%	1,137	57.3%	1,985	100%
Infants Exposed to Mercury	Option A	287	8.9%	1,300	40.1%	1,652	51.0%	3,239	100%
	Option B	293	8.9%	1,331	40.2%	1,687	50.9%	3,311	100%
	Option C	471	7.9%	2,216	36.9%	3,314	55.2%	6,001	100%
	Option D	540	7.5%	2,603	36.1%	4,076	56.5%	7,219	100%
	Option E	591	7.5%	2,839	35.9%	4,469	56.6%	7,898	100%

Source: U.S. EPA Analysis, 2015

The distribution of baseline health effects and health improvements resulting from the ELGs can be compared to the relative share of the population exposed to steam electric pollutants (from *Table 14-3*) to assess the

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Islander anglers have daily consumption rates that are 1.4 times and 1.9 times those of While (non-Hispanic) anglers for recreational and subsistence fishing modes, respectively.

degree to which the regulatory options contribute to mitigating any EJ concerns that may be present in the baseline.

The poor and minority subgroup represents 6.5 percent of the potentially affected population, but accounts for 8.0 percent and 9.3 percent of the estimated IQ point decrements in the exposed population in the baseline. Under Option D, the poor and minority subgroup also sees a disproportional share of the improvements, with 7.8 percent and 7.5 percent of the avoided IQ point decrements from exposure to lead and mercury, respectively. Findings are similar for the poor or minority subgroup, *i.e.*, this subgroup also incurs a disproportionate share of baseline adverse health effects, and of the improvements arising from the final ELGs.

14.4 Subsistence Fishers

In the analysis of health benefits (see *Chapter 3*), EPA assumed that 5 percent of the exposed population are subsistence fishers, and that the remaining 95 percent are recreational anglers. This is based on the assumed 95th percentile fish consumption rate for subsistence fishers. Subsistence fishers consume more self-caught fish than recreational anglers and can therefore be expected to experience higher health risks associated with steam electric pollutants in fish tissue.

The results of the human health analysis suggest that subsistence fishers are disproportionally exposed to pollutants in steam electric power plant discharges via fish consumption and disproportionally incur adverse health effects from this exposure. As shows in *Table 14-6* and *Table 14-7*, subsistence fishers incur 7 percent to 17 percent of the baseline IQ decrements, even though they represent only 5 percent of the overall population, and account for 17 percent to 30 percent of the avoided health effects and benefits of the final rule.

Table 14-6: Distribution of Baseline IQ Point Decrements by Pollutant and Fishing Mode (2021 to 2042)

Pollutant and Exposed Population	Subsistence Fishers (5 percent of population)		Recreational Fishers (95 percent of population)		Total	
Children Exposed to Lead	5,302,873	6.8%	72,840,929	93.2%	78,143,802	100%
Infants Exposed to Mercury	166,415	16.9%	818,907	83.1%	985,322	100%

Source: U.S. EPA Analysis, 2015

Table 14-7: Distribution of Avoided IQ Point Decrements Relative to the Baseline by Fishing Mode, and Pollutant (2021 to 2042)

Pollutant and Exposed Population	Regulatory Option	Subsistence Fishers (5 percent of population)		Recreational Fishers (95 percent of population)		Total	
Children Exposed to Lead	Option A	186	21.8%	667	78.2%	853	100%
	Option B	186	21.8%	667	78.2%	853	100%
	Option C	390	30.4%	895	69.6%	1,285	100%
	Option D	605	30.5%	1,381	69.5%	1,985	100%
	Option E	605	30.5%	1,381	69.5%	1,985	100%

Table 14-7: Distribution of Avoided IQ Point Decrements Relative to the Baseline by Fishing Mode, and Pollutant (2021 to 2042)

Pollutant and Exposed Population	Regulatory Option	Subsistence Fishers (5 percent of population)		Recreational Fishers (95 percent of population)		Total	
Infants Exposed to Mercury	Option A	536	16.5%	2,703	83.5%	3,239	100%
	Option B	548	16.5%	2,763	83.5%	3,311	100%
	Option C	992	16.5%	5,009	83.5%	6,001	100%
	Option D	1,194	16.5%	6,025	83.5%	7,219	100%
	Option E	1,306	16.5%	6,592	83.5%	7,898	100%

Source: U.S. EPA Analysis, 2015

14.5 EJ Analysis Findings

Based on the EJ analyses discussed above, EPA determined that the final ELGs will not deny communities from the benefits of environmental improvements expected to result from compliance with the more stringent effluent limits. In fact, the distribution of avoided adverse health outcomes and benefits suggests that poor and minority communities may receive a greater share of the benefits from the final ELGs than their representation in the affected populations. The final ELGs may thus help redress environmental inequities that may be present in the baseline.

By reducing exposures to pollutants discharged by steam electric power plants, all of the evaluated options would benefit communities with potential EJ concerns. Of the five options, Options C, D, and E are expected to provide significantly greater human health benefits than Options A and B, as indicated by higher reductions in adverse health effects from lead and mercury exposure. Improvements under Option C accrue to poor and minority population to a larger relative extent than do improvements under Options D and E, but Option D (on which the final limitations and standards are based) provides greater benefits overall than Option C, including to poor and minority populations exposed to steam electric pollutants through consumption of self-caught fish. Thus, the final rule will further environmental justice objectives.

14.6 Limitations and Uncertainties

This EJ analysis inherits the limitations and uncertainties of the human health benefit analysis (see *Chapter 3*) regarding pollutant exposure, health effects, and valuation. In addition, however, the analysis also embeds uncertainty derived from the application of uniform assumptions across the population exposed to pollutant discharges when factors may instead vary across socioeconomic characteristics, including:

- EPA assumed that all fishers travel up to 50 miles; in fact, some anglers stay closer to home and certain EJ or sensitive subpopulations may tend to stay closer to home (*e.g.*, poor people and subsistence fishers). These people may be exposed to relatively higher concentrations of pollutants.
- EPA assumed that subsistence fishers are 5 percent of all anglers, with this assumption applied uniformly across all socioeconomic groups. In fact, a relatively higher share of EJ groups may be subsistence fishers. This would tend to increase the inequities already in the baseline and further increase the mitigating effect of the ELGs in addressing these inequities.

- EPA applied uniform fishing participation rates, FCAs, and catch and release practices across the entire population. However, differences in behavior across socioeconomic groups may result in different distribution of baseline impacts and benefits.

In summary, use of average values across the entire US population (or within a state) instead of assumptions that reflect specific socioeconomic conditions may understate inequities present in the baseline and benefits to poor or minority populations, to the extent that different socioeconomic groups may be more likely to be exposed to pollutants from steam electric power plant discharges.

15 References

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Appendix A. Changes to Benefits Analysis since Proposal

The table below summarizes the principal changes EPA made to its benefits analysis for the final rule, as compared to the analysis of the proposed rule (in addition to changes to inputs such as costs and pollutant loads). EPA made changes to address comments it received on the proposed rule analysis and to incorporate updated, more recent data.

Table A-1: Changes to Benefits Analysis Since Proposal

Report Section or Benefit Category	Analysis Component [Proposed rule analysis value]	Changes to Analysis for Final Rule [Final rule analysis value]
General assumptions	Dollar year [all costs and benefits expressed in 2010 dollars]	Updated dollar year [2013]
	Promulgation year [all costs and revenue streams discounted back to 2014]	Updated promulgation year [2015]
	Period of social-costs and benefits analyses [2017-2040]	Updated period of social-costs and benefits analyses [2019-2042]
	Technology implementation years [2017-2021]	Updated technology implementation years [2019-2023]
General pollutant loadings and concentration assumptions	EA modeling of metal concentrations in immediately receiving reaches (national model)	Updated immediately receiving reaches *(see EA for details)*
	RSEI modeling of metal concentrations in immediate and downstream reaches model across nation	Adjusted loadings to reflect partitioning of pollutants in immediate reach, based on the EA national model.
		Used updated baseline that reflects TRI releases for 2012.
	SPARROW modeling of nutrient concentrations in receiving and downstream reaches [estimate changes in ambient pollutant (nutrient) concentrations in receiving and downstream reaches based on regression model]	No changes for nutrients. Estimated changes in suspended sediments and channel deposition using SPARROW
Human health benefits associated with reductions in fish tissue contamination		
Assignment of populations to affected waterbodies to determine potential exposure	Potentially exposed population [people residing within 100 miles of an affected waterbody]	Revised the analysis to focus on Census Block Groups. Subdivided Census Block Group population according to socioeconomic indicators. Used travel distance of 50 miles
	Fishing practices [addressed by consumption estimate]	For recreational anglers, adjusted exposed population to account for catch and release practices
	Scope [immediately receiving reaches only]	Included downstream reaches
Pollutant exposure via consumption of self-caught fish	Consumption rates [uniform consumption rates for recreational/subsistence fishers]	Consumption rates [ethnicity and fishing mode-specific consumption rates]
Avoided IQ losses in children from lead exposure	Exposure estimates and monetization	Updated/verified the dose-response relationship between PbB and IQ based on most recent data for low level exposure (to address comment)

Table A-1: Changes to Benefits Analysis Since Proposal

Report Section or Benefit Category	Analysis Component [Proposed rule analysis value]	Changes to Analysis for Final Rule [Final rule analysis value]
	Monetization	Used updated estimates of the cost of education
Avoided IQ losses in infants from mercury exposure	Exposure estimates [exposed population is infants born to women (15-50 years of age) in households that fish recreationally]	Modified definition of cohort of women of child-bearing age (15-42 years old)
	Monetization	Used updated estimates of the cost of education
Avoided cancer cases from arsenic exposure	Monetization [valuation based on value of statistical life (VSL)]	Changed valuation to use cost of illness (COI) as basis for monetizing avoided cancer cases since skin cancer is generally not fatal
Avoided cardiovascular disease in adults from lead exposure	N/A	Estimated changes in number of CVD (Leggett model) based on ingestion of recreationally-caught fish. Monetization based on VSL
Avoided exposure in drinking water	N/A	Expanded discussion of the potential benefits of reducing pollutant concentrations below MCLs
Other benefits		
Non-market benefits from surface water quality improvements	Data sources	Added changes in suspended solid concentration (from SPARROW) New data for monetization to reflect parameters in new meta-analysis function
	Water quality index	*No change*
	Willingness-to-pay function	Revised meta-analysis to include spatial characteristics of the affected water resources: size of the market, waterbody characteristics (length and flow), availability of substitute sites, land use type in the abutting counties
	Benefitting population	Test alternative definition of the unit of the analysis as the Census Block Group; all households in a given Census Block Group value all water quality changes in a 100 mile radius
Benefits from groundwater quality improvements	Willingness-to-pay for water quality	Did not estimate benefits given promulgation of the final CCR rule
	Avoided human health hazards	
Benefits to threatened and endangered species	Categorical analysis based on habitat overlap/proximity Monetization [willingness to pay]	*No change*
Benefits from avoided impoundment failures	Projected impoundment use at steam electric power plants	Updated to account for projected effects of the CCR rule
	Average failure rate and expected impacts of failures	Expressed risk of failure and impacts for two impoundment categories (small, big) depending on size and failure type
	Residual failure rate	Revised to reflect effects of the CCR rule
	Cleanup costs	Updated to include more recent data and/or more detailed review

Table A-1: Changes to Benefits Analysis Since Proposal

Report Section or Benefit Category	Analysis Component [Proposed rule analysis value]	Changes to Analysis for Final Rule [Final rule analysis value]
	Transaction costs	Updated to include more recent data and/or more detailed review
	Natural resources damages	Updated to include more recent data and/or more detailed review
Reduced emissions of NO_X and SO_2	Changes in air pollutant levels from IPM and engineering analysis Benefit-per-ton estimates for avoided human health impacts	*No change*
Reduced emissions of CO_2	Changes in air pollutant levels from IPM and engineering analysis	*No change*
	Monetization [based on social cost of carbon (SCC) (Interagency Working Group on Social Cost of Carbon, 2010)]	Updated SCC to reflect most recent value in Interagency Working Group on Social Cost of Carbon (2013)
Benefits from reduced water withdrawals	Surface water withdrawals	Expanded qualitative discussion
	Groundwater withdrawals	*No change*
Enhanced CCR marketability for beneficial uses	N/A	Estimated changes in beneficial uses of CCR due to conversions from wet to dry handling. Estimated benefits based on approach used for the final CCR rule analysis.
Avoided maintenance dredging costs	N/A	Estimated reductions in volume of sediment dredged from waterways and reservoirs. Estimated benefits based on the avoided costs for maintenance dredging.
Reduced water treatment costs	Qualitative discussion	Expanded qualitative discussion to provide more information on potential impacts of bromide discharges on disinfection byproducts (and benefits from reducing discharges)
Environmental Justice		
Environmental justice	Profile of affected populations [compare demographic characteristics of population affected by steam electric plant discharges to the state population, using 100-mile buffer distance]	Use Census Block Group as the unit of analysis; use various distance buffers that reflect distance travelled by different socioeconomic groups (1, 3, 15, 30, and 50 miles), based on comments
	N/A	Evaluated EJ considerations across the regulatory options by explicitly analyzing distribution of human health benefits by socioeconomic subgroup

Appendix B. Analysis for Scenario without CPP Rule

EPA included the anticipated effects of the Clean Power Plan (CPP) rule in its baseline for the final ELG rule analysis, as described in *Chapter 1*. This baseline was developed based on information about conversions, retirements, and other changes EPA projected in response to the CPP rule, as proposed by EPA in June 2014. In particular, EPA updated its steam electric power plants profile to account for additional changes due to CPP implementation that affect plant costs for meeting the ELGs and pollutant loads (see *TDD* for details). The results presented in the main body of this document are based on this scenario with CPP.

This appendix presents the results of an alternative benefits analysis using a baseline that does not include the incremental conversions, retirements, and other changes projected to occur in response to the CPP rule. All other assumptions match those described in *Chapters 3* through *10*.

Table B-1. Pollutant Removal for Final ELGs Regulatory Options for Scenario without CPP

Regulatory Option	Pollutant Load Reduction (pounds per year)			
	Conventional Pollutants[a]	Priority Pollutants	Nonconventional Pollutants[b]	Toxic-Weighted Pound Equivalent
Option A	5,810,000	285,000	151,000,000	1,110,000
Option B	5,810,000	386,000	161,000,000	1,250,000
Option C	13,600,000	528,000	377,000,000	1,630,000
Option D	18,500,000	618,000	514,000,000	1,870,000
Option E	19,100,000	665,000	526,000,000	1,910,000

a. The loadings reduction for conventional pollutants includes BOD and TSS.

b. The loadings reduction for nonconventional pollutants excludes TDS and COD to avoid double-counting removals for certain pollutants that would also be measured by these bulk parameters (*e.g.*, sodium, magnesium).

Additionally, under the scenario without CPP, EPA estimates that the final BAT/PSES option (Option D) will reduce surface water withdrawals at steam electric power plants by 209 to 222 billion gallons per year (0.57 to 0.61 million gallons per day) and will avoid withdrawals of 8 million gallons of groundwater per year (21,971 gallons per day).

B.1 Human Health Benefits

B.1.1 Benefits to Children from Reduced Lead Exposure

Table B-2. Estimated Benefits from Avoided IQ Losses for Children Exposed to Lead for Scenario without CPP

Regulatory Option	Average Annual Number of Affected Children 0 to 7	Total Avoided IQ Losses, 2021 to 2042	Annualized Value of Avoided IQ Point Losses[a] (Millions 2013$)			
			3% Discount Rate		7% Discount Rate	
			Low Bound	High Bound	Low Bound	High Bound
Option A	3,326,127	893	$0.35	$0.50	$0.06	$0.09
Option B	3,326,127	893	$0.35	$0.50	$0.06	$0.09
Option C	3,326,127	3,940	$1.57	$2.20	$0.25	$0.38

Table B-2. Estimated Benefits from Avoided IQ Losses for Children Exposed to Lead for Scenario without CPP

Regulatory Option	Average Annual Number of Affected Children 0 to 7	Total Avoided IQ Losses, 2021 to 2042	Annualized Value of Avoided IQ Point Losses[a] (Millions 2013$)			
			3% Discount Rate		7% Discount Rate	
			Low Bound	High Bound	Low Bound	High Bound
Option D	3,326,127	4,693	$1.86	$2.62	$0.30	$0.45
Option E	3,326,127	4,693	$1.86	$2.62	$0.30	$0.45

Source: U.S. EPA Analysis, June 2015

a. Low bound assumes that the loss of one IQ point results in the loss of 1.76% of lifetime earnings (following Schwartz, 1994); high bound assumes that the loss of one IQ point results in the loss of 2.38% of lifetime earnings (following Salkever, 1995).

Table B-3. Estimated Avoided Cost of Compensatory Education for Children with Blood Lead Concentrations above 20 μg/dL and IQ Less than 70[a] for Scenario without CPP

Regulatory Option	Number of Affected Children 0 to 7	Decrease in Number of Cases of IQ < 70, in 2021 to 2042	Avoided Annual Cost (Millions; 2013$)	
			3% Discount Rate	7% Discount Rate
Option A	3,326,127	1	$0.00	$0.00
Option B	3,326,127	1	$0.00	$0.00
Option C	3,326,127	2	$0.01	$0.01
Option D	3,326,127	3	$0.02	$0.01
Option E	3,326,127	3	$0.02	$0.01

Source: U.S. EPA Analysis, June 2015

a. "-" indicates that a value was not estimated and "$0.00" indicates that avoided annual cost is less than $0.01.

B.1.2 Benefits to Adults from Reduced Lead Exposure

Table B-4. Summary of Health Benefits due to Decreased Risk of CVD Mortality during 2019-2042 based on the Economic Value of Avoided Premature Mortality (VSL) for Scenario without CPP

Regulatory Option	Avoided premature deaths	Annualized Benefits (millions 2013$)	
		3 Percent	7 Percent
Option A	11.4	$4.03	$3.36
Option B	11.4	$4.03	$3.36
Option C	48.0	$16.98	$14.17
Option D	62.1	$21.93	$18.30
Option E	62.1	$21.93	$18.30

Source: EPA Analysis, June 2015

B.1.3 Benefits to Children from Reduced Mercury Exposure

Table B-5. Estimated Benefits from Avoided IQ Losses for Infants from Mercury Exposure for Scenario without CPP

Regulatory Option	Number of Affected Infants per Year	Total Avoided IQ Losses, 2021 to 2042	Annualized Value of Avoided IQ Point Losses[a] (Millions 2013$)			
			3% Discount Rate		7% Discount Rate	
			Low Bound	High Bound	Low Bound	High Bound
Option A	418,953	4,519	$1.80	$2.52	$0.29	$0.43
Option B	418,953	4,610	$1.83	$2.57	$0.30	$0.44
Option C	418,953	11,851	$4.71	$6.62	$0.76	$1.14
Option D	418,953	13,351	$5.31	$7.46	$0.86	$1.28
Option E	418,953	14,189	$5.64	$7.92	$0.92	$1.36

Source: U.S. EPA Analysis, 2015

a. Low bound assumes that the loss of one IQ point results in the loss of 1.76 percent of lifetime earnings (following Schwartz, 1994); high bound assumes that the loss of one IQ point results in the loss of 2.38 percent of lifetime earnings (following Salkever, 1995).

B.1.4 Reduced Cancer Cases from Arsenic Exposure

Table B-6. Annual Benefits from Reduced Cancer Cases due to Arsenic Exposure[a] for Scenario without CPP

Regulatory Option	Annual Affected Population	Reduced Cancer Cases, 2019 to 2042	Benefits (Millions 2013$)	
			3% Discount	7% Discount
Option A	35,972,005	0.04	$0.00	$0.00
Option B	35,972,005	0.04	$0.00	$0.00
Option C	35,972,005	0.13	$0.00	$0.00
Option D	35,972,005	0.16	$0.00	$0.00
Option E	35,972,005	0.17	$0.00	$0.00

Source: U.S. EPA Analysis, 2015

a. “-“ indicates that a value was not estimated and “$0.00” indicates that annual benefits are less than $0.01 million.

B.1.5 Total Monetized Human Health Benefits

Table B-7. Total Monetized Human Health Benefits for ELG Options (millions of 2013$)[a,b] for Scenario without CPP

Discount Rate	Option	Reduced Lead Exposure for Children		Reduced Lead Exposure for Adults	Reduced Mercury Exposure for Children		Reduced Cancer Cases from Arsenic	Total	
		Low	High		Low	High		Low	High
3%	A	$0.35	$0.50	$4.03	$1.80	$2.52	$0.00	$6.18	$7.05
	B	$0.35	$0.50	$4.03	$1.83	$2.57	$0.00	$6.21	$7.10
	C	$1.58	$2.21	$16.98	$4.71	$6.62	$0.00	$23.27	$25.81
	D	$1.88	$2.64	$21.93	$5.31	$7.46	$0.00	$29.12	$32.03
	E	$1.88	$2.64	$21.93	$5.64	$7.92	$0.00	$29.45	$32.49
7%	A	$0.06	$0.09	$3.36	$0.29	$0.43	$0.00	$3.71	$3.88
	B	$0.06	$0.09	$3.36	$0.30	$0.44	$0.00	$3.72	$3.89
	C	$0.26	$0.39	$14.17	$0.76	$1.14	$0.00	$15.19	$15.70
	D	$0.31	$0.46	$18.30	$0.86	$1.28	$0.00	$19.47	$20.04
	E	$0.31	$0.46	$18.30	$0.92	$1.36	$0.00	$19.53	$20.12

Source: U.S. EPA Analysis, June 2015

a. "$0.00" indicates that annual benefits are less than $0.01 million.

b. Low bound assumes that the loss of one IQ point results in the loss of 1.76 percent of lifetime earnings (following Schwartz, 1994); high bound assumes that the loss of one IQ point results in the loss of 2.38 percent of lifetime earnings (following Salkever, 1995).

B.1.6 Additional Measures of Human Health Benefits

Table B-8. Reaches Exceeding Human Health Criteria for Steam Electric Pollutants for Scenario without CPP

Regulatory Option	Number of Reaches with Steam Electric Pollutant[a] Concentrations Exceeding Human Health Criteria for at Least One Pollutant	Number of Reaches with Improved Water Quality, Relative to Baseline	
		Number of Reaches with Fewer Exceedances[b]	Number of Reaches with All Exceedances Eliminated
Baseline	3,959	--	--
Option A	,3,334	712	625
Option B	3,334	714	625
Option C	2,400	1,716	1,559
Option D	1,904	2,215	2,055
Option E	1,753	2,303	2,206

Source: U.S. EPA Analysis, 2015

a. Pollutants include arsenic, copper, nickel, selenium, thallium, zinc, cadmium, chromium, lead, and mercury.

b. The number of reaches with exceedances reduced includes those reaches where all exceedances are eliminated.

B.2 Non-Market Benefits for Water Quality Improvements

Table B-9: Total Willingness-to-Pay for Water Quality Improvements

Regulatory Option	Number of Affected Households (Millions)	3% Discount Rate			7% Discount Rate		
		Low	Mean	High	Low	Mean	High
Option A	39.9	$5.1	$6.0	$28.4	$4.0	$4.8	$22.6
Option B	70.4	$15.1	$19.2	$84.4	$12.1	$15.4	$67.3
Option C	76.3	$20.7	$27.8	$115.5	$16.6	$22.3	$92.2
Option D	94.8	$25.8	$35.3	$143.6	$20.6	$28.3	$114.6
Option E	101.4	$27.6	$38.0	$154.0	$22.1	$30.5	$122.9

Source: U.S. EPA Analysis, 2015

B.3 Impacts and Benefits to Threatened and Endangered Species

Table B-10. T&E Species with Habitat Occurring within Waterbodies Affected by Steam Electric Power Plants for Scenario without CPP

Species Group	Species Vulnerability			Species Count
	Low	Moderate	High	
Amphibians	0	4	2	6
Arachnids	4	0	0	4
Birds	10	2	1	13
Clams	0	0	37	37
Crustaceans	0	1	2	3
Fishes	0	0	21	21
Insects	10	2	1	13
Mammals	17	6	1	24
Reptiles	3	1	5	9
Snails	8	0	14	22
Total	**52**	**16**	**84**	**152**

Source: U.S. EPA Analysis, 2015

Table B-11. Estimated Annualized Benefits to T&E Species from WQ Improvements (Millions 2013$)[a,b] for Scenario without CPP

Discount Rate	State	Option A			Option B			Option C			Option D			Option E		
		Low	Medium	High	Low	Medium	High	Low	Medium	High	Low	Medium	High	Low	Medium	High
3%	AL	<$0.01	<$0.01	<$0.01	<$0.01	<$0.01	<$0.01	<$0.01	<$0.01	<$0.01	<$0.01	<$0.01	<$0.01	<$0.01	<$0.01	<$0.01
	GA	<$0.01	$0.01	$0.01	<$0.01	$0.01	$0.01	<$0.01	$0.01	$0.01	<$0.01	$0.01	$0.01	<$0.01	$0.01	$0.01
	MD	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	<$0.01	$0.01	$0.01	<$0.01	$0.01	$0.01	<$0.01	$0.01	$0.01
	SC	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	<$0.01	<$0.01	$0.01	<$0.01	<$0.01	$0.01	<$0.01	<$0.01	$0.01
	Total	**$0.01**	**$0.01**	**$0.02**	**$0.01**	**$0.01**	**$0.02**	**$0.01**	**$0.02**	**$0.03**	**$0.01**	**$0.02**	**$0.03**	**$0.01**	**$0.02**	**$0.03**
7%	AL	<$0.01	<$0.01	<$0.01	<$0.01	<$0.01	<$0.01	<$0.01	<$0.01	<$0.01	<$0.01	<$0.01	<$0.01	<$0.01	<$0.01	<$0.01
	GA	<$0.01	$0.01	$0.01	<$0.01	$0.01	$0.01	<$0.01	$0.01	$0.01	<$0.01	$0.01	$0.01	<$0.01	$0.01	$0.01
	MD	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	<$0.01	$0.01	$0.01	<$0.01	$0.01	$0.01	<$0.01	$0.01	$0.01
	SC	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	<$0.01	<$0.01	<$0.01	<$0.01	<$0.01	<$0.01	<$0.01	<$0.01	<$0.01
	Total	**$0.01**	**$0.01**	**$0.01**	**$0.01**	**$0.01**	**$0.01**	**$0.01**	**$0.02**	**$0.03**	**$0.01**	**$0.02**	**$0.03**	**$0.01**	**$0.02**	**$0.03**

B.4 Benefits from Avoided Impoundment Failures

Table B-12: Steam Electric Impoundments by Size in ELG Baseline for Scenario without CPP

Type	Number of Impoundments		Impoundment Capacity	
	Count	Percent of Total	Total (million gallons)	Percent of Total
Big	732	72%	1,031,833	96%
Small	285	28%	44,202	4%
Total	**1,017**	**100%**	**1,076,036**	**100%**

Table B-13. Estimated Annualized Benefits of Avoided Impoundment Failures by Release Type for Scenario without CPP (Millions; 2013$)[a]

Discount Rate	Regulatory Option	Wall Breaches	Other Releases	All Releases
3%	Option A	$25.3	$9.8	$35.2
	Option B	$25.3	$9.8	$35.2
	Option C	$101.7	$39.4	$141.1
	Option D	$136.3	$52.9	$189.1
	Option E	$136.3	$52.9	$189.1
7%	Option A	$20.3	$7.9	$28.1
	Option B	$20.3	$7.9	$28.1
	Option C	$82.6	$31.9	$114.5
	Option D	$110.6	$42.9	$153.5
	Option E	$110.6	$42.9	$153.5

Source: U.S. EPA Analysis, 2015

a. Baseline value of total failure costs minus option value of total failure costs.

B.5 Air-Related Benefits

Table B-14. Estimated Changes in Electricity Consumption and Air Pollutant Emissions due to Increase in Auxiliary Service at Steam Electric Power Plants, Relative to Baseline for Scenario without CPP

Regulatory Option	Year	Electricity Consumption (MWh)	CO_2 (Metric Tonnes/Year)	NOx (Tons/Year)	SO_2 (Tons/Year)
Option B	2015-2018	0.0	0.0	0.0	0.0
	2019	51,163.2	35,363.6	20.4	37.1
	2020	69,022.4	47,657.8	28.2	51.5
	2021	105,250.1	73,942.8	43.1	75.4
	2022	119,561.0	86,906.2	54.3	81.7
	2023-2042	139,648.1	102,655.1	70.9	93.0

Table B-14. Estimated Changes in Electricity Consumption and Air Pollutant Emissions due to Increase in Auxiliary Service at Steam Electric Power Plants, Relative to Baseline for Scenario without CPP

Regulatory Option	Year	Electricity Consumption (MWh)	CO_2 (Metric Tonnes/Year)	NOx (Tons/Year)	SO_2 (Tons/Year)
Option D	2015-2018	0.0	0.0	0.0	0.0
	2019	95,434.4	68,584.9	48.3	66.1
	2020	146,933.1	101,292.8	80.3	93.3
	2021	223,365.9	153,405.3	112.5	144.4
	2022	270,636.7	191,064.6	146.4	176.0
	2023-2042	339,202.2	238,871.5	193.5	212.4

Source: U.S. EPA Analysis, 2015; see TDD for details.

Table B-15. Estimated Changes in Annual Air Pollutant Emissions due to Increased Trucking at Steam Electric Power Plants, Relative to Baseline for Scenario without CPP

Regulatory Option	Year	CO_2 (Metric Tonnes/Year)	NOx (Tons/Year)	SO_2 (Tons/Year)
Option B	2015-2018	0.0	0.0	0.0
	2019	775.3	0.3	0.0
	2020	918.4	0.4	0.0
	2021	1,092.2	0.5	0.0
	2022	1,143.4	0.5	0.0
	2023-2042	1,218.8	0.5	0.0
Option D	2015-2018	0.0	0.0	0.0
	2019	2,401.2	1.0	0.0
	2020	2,772.4	1.2	0.0
	2021	3,551.3	1.5	0.0
	2022	3,972.7	1.7	0.0
	2023-2042	4,277.3	1.9	0.0

Source: U.S. EPA Analysis, 2015; see TDD for details.

Table B-16. Estimated Changes in Annual Air Pollutant Emissions due to Changes in Electricity Generation Profile, Relative to Baseline for Scenario without CPP

Regulatory Option	Year	CO_2 (Metric Tonnes/Year)	NOx (Tons/Year)	SO_2 (Tons/Year)
With CPP (Also Applied to Without CPP Scenario)				
Option B	2015-2018	0.0	0.0	0.0
	2019-2022	-2,057,293.5	-3,534.5	-4,620.6
	2023-2027	-1,437,164.1	-3,323.9	-527.5
	2028-2033	-246,295.3	-1,361.2	1,315.7
	2034-2042	-1,186,462.9	-1,500.2	-1,608.4

Table B-16. Estimated Changes in Annual Air Pollutant Emissions due to Changes in Electricity Generation Profile, Relative to Baseline for Scenario without CPP

Regulatory Option	Year	CO_2 (Metric Tonnes/Year)	NOx (Tons/Year)	SO_2 (Tons/Year)
Option D	2015-2018	0.0	0.0	0.0
	2019-2022	-4,869,524.3	-14,614.0	-5,662.8
	2023-2027	-2,555,361.0	-11,615.0	2,238.4
	2028-2033	-2,089,591.4	-8,826.0	-984.2
	2034-2042	-3,193,009.0	-10,638.8	-4,243.9

Source: U.S. EPA Analysis, 2015; see TDD for details.

Table B-17. Estimated Net Changes in Air Pollutant Emissions due to Increase in Auxiliary Service at Steam Electric Power Plants, Increased Trucking at Steam Electric Power Plants, and Changes in Electricity Generation Profile, Relative to Baseline for Scenario without CPP

Regulatory Option	Year	CO_2 (Metric Tonnes/Year)	NOx (Tons/Year)	SO_2 (Tons/Year)
Option B	2015-2018	0.0	0.0	0.0
	2019	-2,021,154.6	-3,513.7	-4,583.5
	2020	-2,008,717.3	-3,505.9	-4,569.1
	2021	-1,982,258.5	-3,490.9	-4,545.2
	2022	-1,969,243.9	-3,479.6	-4,538.8
	2023-2027	-1,333,290.2	-3,252.5	-434.5
	2028-2033	-142,421.36	-1,289.73	1,408.69
	2034-2042	-1,082,588.96	-1,428.78	-1,515.47
Option D	2015-2018	0.0	0.0	0.0
	2019	-4,798,538.2	-14,564.6	-5,596.7
	2020	-4,765,459.0	-14,532.5	-5,569.4
	2021	-4,712,567.7	-14,499.9	-5,518.4
	2022	-4,674,486.9	-14,465.9	-5,486.8
	2023-2027	-2,312,212.2	-11,419.6	2,450.9
	2028-2033	-1,846,442.6	-8,630.6	-771.7
	2034-2042	-2,949,860.2	-10,443.5	-4,031.4

Source: U.S. EPA Analysis, 2015

Table B-18. Estimated Benefits from Reduced Air Emissions for Selected Years for Scenario without CPP (millions; 2013$)[a,b]

Option	Year	3% Discount Rate	7% Discount Rate
Option B	2019[c]	$287.2	$265.8
	2020	$290.3	$269.2
	2025	$105.3	$101.4
	2030	-$47.5	-$42.4
Option D	2019[c]	$513.5	$481.3
	2020	$518.7	$487.6
	2025	$83.0	$86.1
	2030	$192.4	$183.7

Source: U.S. EPA Analysis, 2015

a. EPA used SCC values based on a 3 percent (average) discount rate to calculate total benefit values presented for both the 3 percent and 7 percent discount rate.

b. EPA used the changes in annual air pollutant emissions due to changes in electricity generation profile for scenario with CPP (from IPM analysis) when calculating benefits for the scenario without CPP

c. The benefits per ton values used for year 2019 benefit calculation is assumed to be the same as the 2020 benefits per ton values.

Table B-19. Estimated Annualized Benefits from Reduced Air Emissions for Scenario without CPP (Millions; 2013$)[a]

ELG Option	Pollutant		3% Discount Rate	7% Discount Rate
Option B	NO_x		$12.7	$10.6
	SO_2		$44.8	$40.4
	CO_2	3% Avg	$51.9	$51.9
		5% Avg	$15.1	$15.1
		2.5% Avg	$76.5	$76.5
		3% 95th Percentile	$155.9	$155.9
	TOTAL	3% Avg	**$109.3**	**$102.8**
		5% Avg	**$72.6**	**$66.1**
		2.5% Avg	**$134.0**	**$127.4**
		3% 95th Percentile	**$213.4**	**$206.8**
Option D	NO_x		$62.9	$49.3
	SO_2		$81.0	$58.9
	CO_2	3% Avg	$138.4	$138.4
		5% Avg	$40.0	$40.0
		2.5% Avg	$204.7	$204.7
		3% 95th Percentile	$416.9	$416.9
	TOTAL	3% Avg	**$282.4**	**$246.7**
		5% Avg	**$183.9**	**$148.3**
		2.5% Avg	**$348.6**	**$313.0**
		3% 95th Percentile	**$560.8**	**$525.2**

Source: U.S. EPA Analysis, 2015

a. EPA used the changes in annual air pollutant emissions due to changes in electricity generation profile for scenario with CPP (from IPM analysis) when calculating benefits for the scenario without CPP

B.6 Benefits from Reduced Water Withdrawals

Table B-20. Estimated Annualized Benefits from Reduced Groundwater Withdrawals (Millions; 2013$)

Regulatory Option	Reduction in Groundwater Intakes (million gallons per year; full implementation)	3% Discount Rate	7% Discount Rate
Option A	0.0	$0.00	$0.00
Option B	0.0	$0.00	$0.00
Option C	0.0	$0.00	$0.00
Option D	8.0	$0.02	$0.02
Option E	8.0	$0.02	$0.02

Source: U.S. EPA Analysis, 2015

B.7 Benefits from Enhanced Marketability of Coal Combustion Residuals

Table B-212. State-level Market Approximation (Short Tons).

Application	Baseline Production		Changes due to ELGs	
	Production	Unmet Demand (% of production)	Fly Ash (% ΔCCR)	Bottom Ash (% ΔCCR)
Concrete	13,400,062	3,277,184 (24%)	166,535 (9.6%)	-
Fill	320,701,683	312,705,505 (98%)	1,575,450 (90.4%)	5,480,176 (92.7%)

Source: U.S. EPA Analysis 2015

Table B-23. Estimated Beneficial Use Applications of CCRs, by CCR Category

ELG Option and CCR Category	Beneficial Use Application (1,000 short tons)	
	Concrete	Structural Fill
Option A or Option B		
Fly ash	167	1,575
Bottom ash	NA	0
Total	***167***	***1,575***
Option C		
Fly ash	167	1,575
Bottom ash	NA	3,431
Total	***167***	***5,006***
Option D or Option E		
Fly ash	167	1,575
Bottom ash	NA	4,821
Total	***167***	***6,397***

Table B-224. Annual Avoided Resource and Environmental Impacts Given CCR Reuse in Concrete and Fill Applications for Scenario Without CPP

Impact Category	Fly Ash	Bottom Ash	Option Total	CCR RIA, 2030 3-yr rolling avg
Option A or Option B				
Concrete (mill. tons)	0.167	NA	0.167	0.21
Structural fill (mill. tons)	1.58	0	1.58	6.93
Energy (MMBtu)	657,548	0	657,548	910,000
Water (million gal)	1,937	0	1,937	21,000
Greenhouse gases (tons)	1,442,070	0	1,442,070	75,000
NOx (tons)	359	0	359	310
SOx (tons)	54	0	54	59
Option C				
Concrete (mill. tons)	0.167	NA	0.167	0.21
Structural fill (mill. tons)	1.58	3.43	5.06	6.93
Energy (MMBtu)	657,548	137,232	794,780	910,000
Water (million gal)	1,937	4,144	6,081	21,000
Greenhouse gases (tons)	1,442,070	10,979	1,453,048	75,000
NOx (tons)	359	92	451	310
SOx (tons)	54	29	83	160
Option D or Option E				
Concrete (mill. tons)	0.167	NA	0.167	0.21
Structural fill (mill. tons)	1.58	4.82	6.39	6.93
Energy (MMBtu)	657,548	192,848	850,396	910,000
Water (million gal)	1,937	5,824	7,761	21,000
Greenhouse gases (tons)	1,442,070	15,428	1,457,498	75,000
NOx (tons)	359	129	488	310
SOx (tons)	54	41	95	160

Note: Values in this table represent annual changes in a full-compliance year (*e.g.*, starting in 2023).

Table B-25. Annualized Economic Value of Estimated Changes in Beneficial Use (Million 2013$).

Regulatory Option	Impact Category	3%	7%
Option A or Option B	Avoided Disposal Costs to Steam Electric Plants	$6.44	$5.46
	Beneficiation Costs	-$0.21	-$0.16
	Avoided Life Cycle Costs of Virgin Materials	$11.34	$14.52
	Net Social Value	**$17.57**	**$19.82**
Option C	Avoided Disposal Costs to Steam Electric Plants	$21.97	$18.39
	Beneficiation Costs	-$0.21	-$0.16
	Avoided Life Cycle Costs of Virgin Materials	$13.25	$16.69
	Net Social Value	**$35.01**	**$34.92**
Option D or Option E	Avoided Disposal Costs to Steam Electric Plants	$34.43	$28.59
	Beneficiation Costs	-$0.21	-$0.16
	Avoided Life Cycle Costs of Virgin Materials	$13.94	$17.48
	Net Social Value	**$48.16**	**$45.90**

Notes: Annualized over 24 years (2015 - 2042). Values escalated using CCI and GDP through 2022; thereafter, assume no real change in prices above inflation. Avoided disposal costs to steam electric power plants include annual O&M costs.

B.8 Total Monetized Benefits

Table B-26. Summary of Total Annualized Benefits at 3 Percent (Millions; 2013$)

Benefit Category	Option A			Option B			Option C			Option D			Option E		
	Low	Mid[f]	High	Low	Mid[f]	High	Low	Mid[f]	High	Low	Mid[f]	High	Low	Mid[f]	High
Human Health Benefits	**$6.2**	**$6.6**	**$7.1**	**$6.2**	**$6.7**	**$7.1**	**$23.3**	**$24.5**	**$25.8**	**$29.1**	**$30.6**	**$32.0**	**$29.4**	**$31.0**	**$32.5**
Reduced IQ losses in children from exposure to lead[a]	$0.4	$0.4	$0.5	$0.4	$0.4	$0.5	$1.6	$1.9	$2.2	$1.9	$2.3	$2.6	$1.9	$2.3	$2.6
Reduced CVD in adults from exposure to lead	$4.0			$4.0			$17.0			$21.9			$21.9		
Reduced IQ losses in children from exposure to mercury[a]	$1.8	$2.2	$2.5	$1.8	$2.2	$2.6	$4.7	$5.7	$6.6	$5.3	$6.4	$7.5	$5.6	$6.8	$7.9
Avoided cancer cases from exposure to arsenic[b]	$0.0			$0.0			$0.0			$0.0			$0.0		
Improved Ecological Conditions and Recreational Uses	**$5.1**	**$6.1**	**$28.4**	**$15.2**	**$19.2**	**$84.4**	**$20.7**	**$27.8**	**$115.5**	**$25.8**	**$35.3**	**$143.7**	**$27.6**	**$38.0**	**$154.0**
Use and nonuse values for water quality improvements	$5.1	$6.0	$28.4	$15.1	$19.2	$84.4	$20.7	$27.8	$115.5	$25.8	$35.3	$143.6	$27.6	$38.0	$154.0
Nonuse values of T&E species[b]	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
Market and Productivity Benefits	**$52.7**			**$52.7**			**$176.1**			**$237.3**			**$237.3**		
Avoided impoundment failures	$35.2			$35.2			$141.1			$189.1			$189.1		
Reduced dredging costs[b]	$0.0			$0.0			$0.0			$0.0			$0.0		
Ash marketing benefits	$17.6			$17.6			$35.0			$48.2			$48.2		
Air-related benefits	**NE**			**$109.4**			**NE**			**$282.4**			**NE**		
Reduced human health effects	NE			$57.5			NE			$143.9			NE		
Reduced CO_2 emissions[c]	NE			$51.9			NE			$138.4			NE		
Reduced water withdrawals[b]	**$0.0**			**$0.0**			**$0.0**			**$0.0**			**$0.0**		
Total (excluding air-related Benefits)[d]	**$64.0**	**$65.4**	**$88.2**	**$74.1**	**$78.6**	**$144.3**	**$220.1**	**$228.4**	**$317.4**	**$292.2**	**$303.2**	**$413.0**	**$294.4**	**$306.3**	**$423.8**
Total (including air-related Benefits)[d,e]	**NE**	**NE**	**NE**	**$183.5**	**$188.0**	**$253.6**	**NE**	**NE**	**NE**	**$574.6**	**$585.5**	**$695.4**	**NE**	**NE**	**NE**

Source: U.S. EPA Analysis, 2015

Table B-26. Summary of Total Annualized Benefits at 3 Percent (Millions; 2013$)

Benefit Category	Option A			Option B			Option C			Option D			Option E		
	Low	Mid[f]	High	Low	Mid[f]	High	Low	Mid[f]	High	Low	Mid[f]	High	Low	Mid[f]	High

“NE” indicates that EPA did not estimate the benefits. Air-related benefits of Option A are expected to be less than those for Option B; air-related benefits for Option C are expected to be between those of Options B and D; and air-related benefits of Option E are expected to be greater than those for Option D.

a. Value includes reduced IQ losses and avoided cost of compensatory education in children from exposure to lead. For details see *Chapter 3*.

b. “< $0.1” indicates that the monetized annual benefits are positive but less than $0.1 million.

c. For the valuation of benefits from reductions in CO_2 emissions EPA relied on the 3 percent average social cost of carbon estimate.

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

e. The total monetized benefits for options A, C, and E do not include air-related benefits. This category of benefits was analyzed for Options B and D only (see *Chapter 7*).

f. EPA estimated use and nonuse values for water quality improvements using two different meta-regression models of willingness-to-pay. One model provides the low and high bounds while a different model provides a central estimate (included in this table in the mid-range column). For this reason, the mid-range estimate differs from the midpoint of the range for this benefit category. For details, see *Chapter 4*.

Table B-27. Summary of Total Annualized Benefits at 7 Percent (Millions; 2013$)

Benefit Category	Option A			Option B			Option C			Option D			Option E		
	Low	**Mid[f]**	**High**	**Low**	**Mid[f]**	**High**	**Low**	**Mid[f]**	**High**	**Low**	**Mid[f]**	**High**	**Low**	**Mid[f]**	**High**
Human Health Benefits	**$3.7**	**$3.8**	**$7.2**	**$3.7**	**$3.8**	**$22.2**	**$15.2**	**$15.4**	**$15.7**	**$19.5**	**$19.8**	**$20.0**	**$19.5**	**$19.8**	**$20.1**
Reduced IQ losses in children from exposure to lead[a]	$0.1	$0.1	$0.1	$0.1	$0.1	$0.1	$0.3	$0.3	$0.4	$0.3	$0.4	$0.5	$0.3	$0.4	$0.5
Reduced CVD in adults from exposure to lead	$3.4			$3.4			$14.2			$18.3			$18.3		
Reduced IQ losses in children from exposure to mercury[a]	$0.3	$0.4	$3.8	$0.3	$0.4	$18.7	$0.8	$1.0	$1.1	$0.9	$1.1	$1.3	$0.9	$1.1	$1.4
Avoided cancer cases from exposure to arsenic[b]	$0.0			$0.0			$0.0			$0.0			$0.0		
Improved Ecological Conditions and Recreational Uses	**$4.1**	**$4.8**	**$22.6**	**$12.1**	**$15.4**	**$67.3**	**$16.6**	**$22.3**	**$92.2**	**$20.6**	**$28.3**	**$114.6**	**$22.1**	**$30.5**	**$122.9**
Use and nonuse values for water quality improvements	$4.0	$4.8	$22.6	$12.1	$15.4	$67.3	$16.6	$22.3	$92.2	$20.6	$28.3	$114.6	$22.1	$30.5	$122.9
Nonuse values of T&E species[b]	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
Market and Productivity Benefits	**$47.9**			**$47.9**			**$149.4**			**$199.4**			**$199.4**		
Avoided impoundment failures	$28.1			$28.1			$114.5			$153.5			$153.5		
Reduced dredging costs[b]	$0.0			$0.0			$0.0			$0.0			$0.0		
Ash marketing benefits	$19.8			$19.8			$34.9			$45.9			$45.9		
Air-Related Benefits	**NE**			**$102.8**			**NE**			**$246.7**			**NE**		
Reduced human health effects	NE			$50.92			NE			$108.28			NE		
Reduced CO_2 emissions[c]	NE			$51.85			NE			$138.42			NE		
Reduced water withdrawals[b]	**$0.0**			**$0.0**			**$0.0**			**$0.0**			**$0.0**		
Total (excluding air-related Benefits)[d]	**$55.7**	**$56.6**	**$77.7**	**$63.7**	**$67.1**	**$137.4**	**$181.2**	**$187.2**	**$257.4**	**$239.5**	**$247.5**	**$334.1**	**$241.0**	**$249.8**	**$296.5**
Total (including air-related Benefits)[d,e]	**NE**	**NE**	**NE**	**$166.5**	**$169.9**	**$240.2**	**NE**	**NE**	**NE**	**$486.2**	**$494.2**	**$580.8**	**NE**	**NE**	**NE**

Source: U.S. EPA Analysis, 2015

"NE" indicates that EPA did not estimate the benefits. Air-related benefits of Option A are expected to be less than those for Option B; air-related benefits for Option C are expected to be between those of Options B and D; and air-related benefits of Option E are expected to be greater than those for Option D.

a. Value includes reduced IQ losses and avoided cost of compensatory education in children from exposure to lead. For details see *Chapter 3*.

b. "< $0.1" indicates that the monetized annual benefits are positive but less than $0.1 million.

Table B-27. Summary of Total Annualized Benefits at 7 Percent (Millions; 2013$)

Benefit Category	Option A			Option B			Option C			Option D			Option E		
	Low	Mid[f]	High	Low	Mid[f]	High	Low	Mid[f]	High	Low	Mid[f]	High	Low	Mid[f]	High

c. For the valuation of benefits from reductions in CO_2 emissions EPA relied on the 3 percent average social cost of carbon estimate.

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

e. The total monetized benefits for options A, C, and E do not include air-related benefits. This category of benefits was analyzed for Options B and D only (see *Chapter 7*).

f. EPA estimated use and nonuse values for water quality improvements using two different meta-regression models of willingness-to-pay. One model provides the low and high bounds while a different model provides a central estimate (included in this table in the mid-range column). For this reason, the mid-range estimate differs from the midpoint of the range for this benefit category. For details, see *Chapter 4*.

Table B-28: Time Profile of Benefits at 3 Percent (Millions; 2013$) (Including Air-Related Benefits for Options B and D) for Scenario Without CPP

Year	Option A[a]	Option B	Option C[a]	Option D	Option E[a]
2015	$0.0	$0.0	$0.0	$0.0	$0.0
2016	$0.0	$0.0	$0.0	$0.0	$0.0
2017	$0.0	$0.0	$0.0	$0.0	$0.0
2018	$0.0	$0.0	$0.0	$0.0	$0.0
2019	$10.6	$297.9	$27.7	$555.8	$42.3
2020	$13.2	$303.5	$83.6	$630.0	$111.3
2021	$30.6	$337.8	$138.0	$714.3	$197.5
2022	$48.9	$360.5	$244.3	$833.9	$310.8
2023	$85.6	$202.5	$295.2	$471.8	$396.2
2024	$86.5	$205.5	$298.2	$477.4	$400.0
2025	$86.9	$208.0	$299.0	$480.2	$401.0
2026	$87.1	$210.4	$299.1	$482.3	$401.1
2027	$87.2	$212.7	$298.8	$483.7	$400.7
2028	$87.3	$57.5	$298.3	$583.9	$399.9
2029	$87.2	$56.9	$297.4	$583.9	$398.8
2030	$87.1	$56.3	$296.6	$586.2	$397.7
2031	$87.2	$56.0	$295.9	$588.0	$396.7
2032	$87.2	$55.6	$295.1	$590.1	$395.7
2033	$87.2	$55.2	$294.4	$592.3	$394.8
2034	$87.3	$250.6	$293.8	$827.4	$393.9
2035	$87.3	$253.1	$293.3	$833.1	$393.2
2036	$87.4	$255.6	$292.9	$838.9	$392.6
2037	$87.5	$258.1	$292.5	$844.8	$392.1
2038	$87.7	$260.6	$292.2	$850.8	$391.6
2039	$87.8	$263.1	$291.9	$856.8	$391.3
2040	$87.9	$265.7	$291.8	$863.0	$391.0
2041	$88.1	$268.3	$291.7	$869.2	$390.8
2042	$88.2	$269.6	$291.5	$872.2	$390.6
Annualized Benefits, 3%	**$65.4**	**$188.0**	**$228.4**	**$585.5**	**$306.3**

Source: U.S. EPA Analysis, 2015

a. Estimates for Options A, C and E do not include air-related benefits. This category of benefits was only estimated for Options B and D (see *Chapter 7*).

Table B-29: Time Profile of Benefits at 7 Percent (Millions; 2010$) (Including Air-Related Benefits for Options B and D) for Scenario Without CPP

Year	Option A[a]	Option B	Option C[a]	Option D	Option E[a]
2015	$0.0	$0.0	$0.0	$0.0	$0.0
2016	$0.0	$0.0	$0.0	$0.0	$0.0
2017	$0.0	$0.0	$0.0	$0.0	$0.0
2018	$0.0	$0.0	$0.0	$0.0	$0.0
2019	$10.6	$276.5	$27.7	$523.6	$42.3

Table B-29: Time Profile of Benefits at 7 Percent (Millions; 2010$) (Including Air-Related Benefits for Options B and D) for Scenario Without CPP

Year	Option A[a]	Option B	Option C[a]	Option D	Option E[a]
2020	$13.2	$282.4	$83.6	$598.9	$111.3
2021	$28.2	$314.1	$131.1	$674.4	$189.2
2022	$46.5	$336.8	$237.2	$794.0	$302.4
2023	$83.2	$196.2	$288.1	$467.1	$387.7
2024	$84.0	$199.2	$291.0	$472.6	$391.4
2025	$84.4	$201.6	$291.8	$475.1	$392.3
2026	$84.6	$204.1	$291.8	$477.2	$392.4
2027	$84.7	$206.3	$291.5	$478.6	$391.9
2028	$84.7	$60.1	$290.8	$566.8	$391.0
2029	$84.6	$59.4	$289.9	$566.7	$389.9
2030	$84.5	$58.8	$289.0	$568.8	$388.7
2031	$84.6	$58.5	$288.2	$570.6	$387.6
2032	$84.6	$58.1	$287.4	$572.6	$386.5
2033	$84.6	$57.7	$286.7	$574.7	$385.5
2034	$84.6	$240.6	$286.0	$794.8	$384.6
2035	$84.6	$243.1	$285.4	$800.4	$383.8
2036	$84.7	$245.5	$284.9	$806.1	$383.1
2037	$84.8	$248.0	$284.5	$811.9	$382.5
2038	$84.9	$250.5	$284.1	$817.8	$382.0
2039	$85.0	$253.0	$283.8	$823.8	$381.5
2040	$85.1	$255.5	$283.6	$829.8	$381.2
2041	$85.3	$258.1	$283.4	$836.0	$380.9
2042	$85.3	$259.4	$283.2	$838.8	$380.6
Annualized Benefits, 7%	**$56.6**	**$169.9**	**$187.2**	**$494.2**	**$249.8**

Source: U.S. EPA Analysis, 2015

a. Estimates for Options A, C and E do not include air-related benefits. This category of benefits was only estimated for Options B and D (see *Chapter 7*).

B.9 Total Costs

Table B-30: Summary of Annualized Costs for Scenario without CPP (Millions; $2013)

Regulatory Option	3% Discount Rate	7% Discount Rate
Option A	$141.1	$137.1
Option B	$238.9	$234.9
Option C	$465.3	$461.4
Option D	$640.5	$626.1
Option E	$711.8	$695.8

Source: U.S. EPA Analysis, 2015.

Table B-31: Time Profile of Costs to Society (Millions; $2013), Scenario Without CPP

Year	Option A	Option B	Option C	Option D	Option E
2015	$0.0	$0.0	$0.0	$0.0	$0.0
2016	$0.0	$0.0	$0.0	$0.0	$0.0
2017	$0.0	$0.0	$0.0	$0.0	$0.0
2018	$0.0	$0.0	$0.0	$0.0	$0.0
2019	$474.6	$820.7	$1,420.3	$1,758.7	$1,900.2
2020	$169.2	$377.9	$855.0	$1,218.1	$1,388.1
2021	$431.3	$696.7	$1,347.4	$1,657.5	$1,809.6
2022	$223.1	$415.8	$1,043.8	$1,367.5	$1,597.5
2023	$355.8	$618.1	$1,367.7	$1,843.9	$2,035.9
2024	$85.8	$141.8	$258.5	$391.0	$434.6
2025	$95.9	$151.9	$268.5	$401.8	$446.9
2026	$91.3	$147.3	$265.2	$401.5	$446.8
2027	$93.8	$149.8	$265.6	$400.0	$445.1
2028	$90.2	$146.2	$263.8	$398.0	$443.8
2029	$98.4	$154.4	$279.0	$419.2	$464.6
2030	$96.3	$152.3	$275.0	$414.1	$457.7
2031	$99.3	$155.2	$279.7	$419.0	$464.1
2032	$97.9	$153.9	$277.7	$416.8	$462.1
2033	$98.7	$154.7	$279.8	$420.4	$465.5
2034	$88.3	$144.2	$261.7	$395.6	$441.3
2035	$95.7	$151.7	$269.6	$404.1	$449.5
2036	$91.8	$147.8	$267.7	$404.2	$447.8
2037	$96.2	$152.2	$271.2	$407.8	$452.9
2038	$93.8	$149.8	$271.1	$408.9	$453.9
2039	$97.8	$153.8	$277.2	$415.4	$460.0
2040	$97.0	$153.0	$273.9	$411.3	$456.0
2041	$97.0	$153.0	$273.7	$409.1	$453.4
2042	$96.3	$152.3	$271.7	$405.2	$448.8
Annualized Costs, 3%	**$141.1**	**$238.9**	**$465.3**	**$640.5**	**$711.8**
Annualized Costs, 7%	**$137.1**	**$234.9**	**$461.4**	**$626.1**	**$695.8**

Source: U.S. EPA Analysis, 2015.

B.10 Monetized Benefits and Costs Comparison

B.10.1 Comparison of Total Monetized Benefits and Costs

Table B-32. Total Annualized Benefits and Costs by Regulatory Option and Discount Rate (Millions; 2013$)

Regulatory Option	Total Monetized Benefits			Total Monetized Benefits, Including Extrapolated Values[a]			Total Costs
	Low	Mid	High	Low	Mid	High	
3% Discount Rate							
Option A	$64.0	$65.4	$88.2	$145.4	$144.7	$152.8	$141.1
Option B	$183.5	$188.0	$253.6	$183.5	$188.0	$253.6	$238.9
Option C	$220.1	$228.4	$317.4	$499.9	$505.3	$549.8	$465.3
Option D	$574.6	$585.5	$695.4	$574.6	$585.5	$695.4	$640.5
Option E	$294.4	$306.3	$423.8	$668.6	$677.6	$734.0	$711.9
7% Discount Rate							
Option A	$55.7	$56.6	$77.7	$126.5	$125.1	$134.6	$137.1
Option B	$166.5	$169.9	$240.2	$166.5	$169.9	$240.2	$234.9
Option C	$181.2	$187.2	$257.4	$411.5	$414.1	$445.8	$461.4
Option D	$486.2	$494.2	$580.8	$486.2	$494.2	$580.8	$626.1
Option E	$241.0	$249.8	$296.5	$547.4	$552.6	$513.6	$695.8

Source: U.S. EPA Analysis, 2015.

a. EPA did not analyze air-related benefits for Options A, C, and E. This category of benefits was only estimated for Options B and D (see *Chapter 7*). EPA adjusted the total benefits estimated for Options A, C and E by multiplying the totals without air-related benefits by the average ratio of [total with air-related benefits]/[total without air-related benefits] for Options B and D.

B.10.2 Analysis of Incremental Monetized Benefits and Costs

Table B-33. Incremental Net Benefit Analysis for Scenario without CPP (Millions; 2013$)

Regulatory Option[a]	Total Annual Monetized Benefits, Including Adjusted or Inferred Values			Total Social Costs	Net Annual Monetized Benefits[a]			Incremental Net Annual Monetized Benefits[b]		
	Low	Mid[d]	High		Low	Mid[d]	High	Low	Mid[d]	High
3% Discount Rate										
Option A	$145.4	$144.7	$152.8	$141.1	$4.3	$3.6	$11.7	-	-	-
Option B	$183.5	$188.0	$253.6	$238.9	-$55.4	-$50.9	$14.7	-$59.7	-$54.5	$3.0
Option C	$499.9	$505.3	$549.8	$465.3	$34.6	$40.0	$84.5	$90.0	$90.9	$69.8
Option D	$574.6	$585.5	$695.4	$640.5	-$65.9	-$55.0	$54.9	-$100.5	-$95.0	-$29.7
Option E	$668.6	$677.6	$734.0	$711.9	-$43.3	-$34.3	$22.1	$22.7	$20.7	-$32.7
7% Discount Rate										
Option A	$126.5	$125.1	$134.6	$137.1	-$10.6	-$12.0	-$2.5	-	-	-
Option B	$166.5	$169.9	$240.2	$234.9	-$68.4	-$65.0	$5.3	-$57.8	-$53.0	$7.7
Option C	$411.5	$414.1	$445.8	$461.4	-$49.9	-$47.3	-$15.6	$18.5	$17.6	-$20.9

Table B-33. Incremental Net Benefit Analysis for Scenario without CPP (Millions; 2013$)

Regulatory Option[a]	Total Annual Monetized Benefits, Including Adjusted or Inferred Values			Total Social Costs	Net Annual Monetized Benefits[a]			Incremental Net Annual Monetized Benefits[b]		
	Low	Mid[d]	High		Low	Mid[d]	High	Low	Mid[d]	High
Option D	$486.2	$494.2	$580.8	$626.1	-$139.9	-$131.9	-$45.3	-$90.0	-$84.6	-$29.7
Option E	$547.4	$552.6	$513.6	$695.8	-$148.4	-$143.2	-$182.2	-$8.5	-$11.3	-$136.9

Source: U.S. EPA Analysis, 2015.

a. EPA did not analyze air-related benefits for Options A, C, and E. This category of benefits was only estimated for Options B and D (see *Chapter 7*). EPA adjusted the total benefits estimated for Options A, C, and E by multiplying the totals without air-related benefits by the average ratio of [total with air-related benefits]/[total without air-related benefits] for Options B and D.

b. Net benefits are calculated by subtracting total annualized costs from total annual monetized benefits.

c. Incremental net benefits are equal to the difference between net benefits of an option and net benefits of the previous, less stringent option.

d. EPA estimated use and nonuse values for water quality improvements using two different meta-regression models of WTP. One model provides the low and high bounds while a different model provides the mid estimate. For this reason, the mid benefit estimate differs from the midpoint of the benefits range. For details, see Chapter 4.

Appendix C. Estimation of Exposed Population

The assessment uses the Census Block Group as the geographic unit of analysis, assigning a radial distance (*e.g.*, 50 miles or 100 miles) from the Census Block Group centroid. EPA assumes that all modeled reaches within this range are viable fishing sites, with all unaffected reaches viable substitutes for affected reaches within the area around the Census Block Group.

By focusing on distance from the Census Block Group, rather than distances from affected reaches, each household is only included in the assessment once, eliminating the potential for double-counting of households that are near multiple affected waterbodies.

Figure C-1 presents a hypothetical example focusing on two Census Block Groups (square at the center of each circular area), each near five waterbodies with water quality changes under the ELGs (thick red lines).

The same approach is used to identify populations for the analysis of non-market benefits in *Chapter 4*. In that case, the circles represent the outer edge of the 100-mile buffer around each block group. Highlighted in red are the affected NHD reaches under regulatory options for which baseline WQI and ΔWQI would be estimated

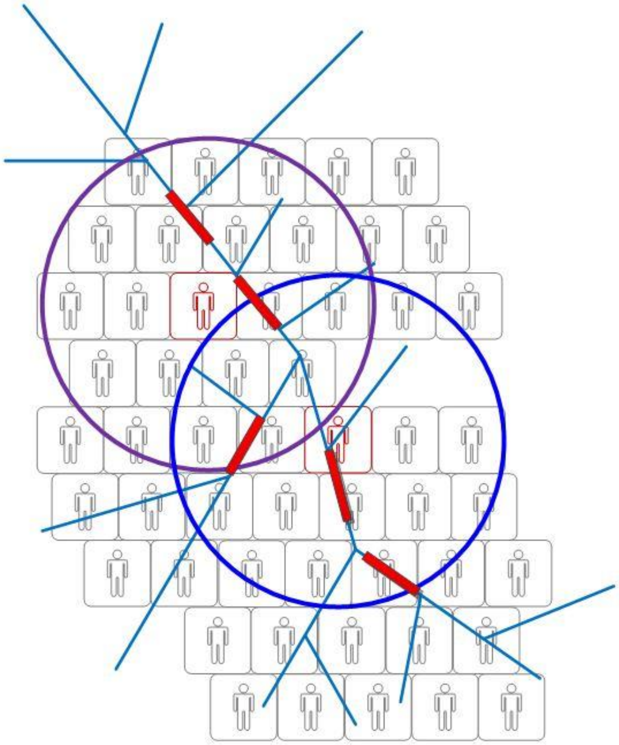

Figure C-1. Illustration of Intersection of Census Block Groups and COMIDs.

Appendix D. Derivation of Ambient Water and Fish Tissue Concentrations in Receiving and Downstream Reaches

This appendix describes the methodology EPA used to estimate in-stream and fish tissue concentrations under the baseline and each of the five ELG regulatory options. The concentrations are used as inputs to estimate the water quality improvements and human health benefits of the final rule. Specifically, EPA in-stream metal concentrations to analyze non-use benefits of water quality improvements (see *Chapter 4*), and to derive fish tissue concentrations used to analyze human health effects from consuming self-caught fish (see *Chapter 3*). Nutrient and suspended sediment concentrations are used to support analysis of non-use benefits from water quality improvements (see *Chapter 4*).

The overall modeling methodology is similar to that used at proposal (see Chapter 4 in U.S. EPA (2013a)) and builds on data and methods described in the Technical Development Document and Environmental Assessment documents for the final ELGs (U.S. EPA, 2015a; 2015b). The following sections discuss calculations of the metal concentrations in streams and fish tissue and nutrient and sediment concentrations in streams.

D.1 Metals

D.1.1 Estimating Water Concentrations in each Reach

EPA first estimated the baseline and post-compliance metal concentrations in reaches receiving steam electric power plant discharges and downstream reaches.

The water quality model component of EPA’s *Risk-Screening Environmental Indicators* (RSEI) model (U.S. EPA, 2012c) 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 National Hydrographic Dataset (NHD).[86] The hydrography network represented in RSEI consists of approximately 2.5 million reaches (unique COMIDs).[87]

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[86] RSEI utilizes the USGS’s National Hydrology Dataset (NHD) which 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. The NHD reaches in this analysis range from 0.003 miles to 9.11 miles in length.

[87] Reaches represented in RSEI are those determined to be potentially fishable based on type and physical characteristics. As documented in U.S. EPA (2012c): “Certain criteria were applied to the NHDPlus dataset to select the reaches to be used in the model. Specifically, because RSEI calculates the movement of a chemical release downstream using flow and velocity data, qualifying reaches must have at least one downstream or upstream connecting reach and have a non-negative flow and velocity. RSEI will not calculate concentrations for certain types of reaches, such as coastlines, treatment reservoirs, and bays; the downstream path of any chemical is assumed to stop if one of these types of reach is encountered. Additionally, some types of reaches are excluded from the set of fishable reaches, such as pipelines, aqueducts, and certain types of reservoirs. NHDPlus does not separate canals (presumably fishable) and ditches (presumably not fishable), so RSEI excludes reaches in the canal/ditch category if the annual mean flow is less than 5 ft^3/s. This is an arbitrary minimum, and is intended primarily to exclude ditches at the point of the facility discharge. For reaches designated as not fishable in NHDPlus, the chemical is still assumed to travel downstream to the next reach, which may or may not be fishable.”

The analysis involved the following key steps for the baseline and each of the five regulatory options:

- **Summing plant-level loadings to the COMID**. EPA summed the plant-level annual average loads (see TDD) for each unique COMID receiving plant discharges from steam electric power plants in the baseline. Chapter 4 in the EA report describes the approach EPA used to identify the receiving waterbodies (U.S. EPA 2015a).
- **Specifying loads in the water quality model**. RSEI includes data on annual average pollutant loadings to surface waters from facilities that reported to the Toxic Release Inventory (TRI) in 2012. EPA replaced the loadings provided for Steam Electric plant dischargers in the TRI data set with those obtained in Step 1. Loadings for other TRI reporters were left unchanged.
- **Performing dilution and transport calculations**. RSEI's water quality model uses a simple dilution and first-order decay equation (where metals are treated as conservative substances) to estimate average annual water concentrations for each individual reach. In the model, a plant is assumed to release its annual load at a constant rate throughout the year. Each source-pollutant release is tracked downstream throughout the NHD reach network until one of three conditions occurs: 1) the release has traveled 300 km (186 miles) downstream; 2) the release has traveled a distance equivalent to one week of travel time; or 3) the concentration reaches 1×10^{-9} mg/L. The 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 reach mean flow (provided in NHDPlus as an attribute of each COMID).

EPA used the approach above to estimate annual average concentrations of ten metals: arsenic, cadmium, chromium VI, copper, lead, mercury, nickel, selenium, thallium, and zinc. The results show that, of the 2.5 million reaches represented in RSEI:

- 77,414 reaches (117,518 km) have non-zero concentrations, and
- 18,773 of these reaches (27,778 km) are affected by steam electric power plant discharges in the baseline.

D.1.2 Estimating Fish Tissue Concentrations in each Reach

To support analysis of the human health benefits associated with water quality improvements (see *Chapter 3*), EPA estimated concentrations of arsenic, lead, and mercury in fish tissue based on the RSEI model outputs discussed above.

The methodology follows the same general approach described in the EA document for estimating fish tissue concentrations for receiving reaches (U.S. EPA, 2015a), but applies the calculations to the larger set of reaches modeled using RSEI, which include not only the receiving reaches analyzed in the EA, but also downstream reaches. Further, the calculations use RSEI-estimated concentrations as inputs, which account not only for the steam electric discharges, but also other major dischargers that report to TRI.

The analysis involved the following key steps for the baseline and each of the five regulatory options:

- **Obtaining the relationship between water concentrations and fish tissue concentrations**. EPA used the results of the EA national model 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 metals.
- **Calculating fish tissue data for affected reaches**. For reaches for which RSEI 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 metal.

- **Imputing the fish tissue concentrations for all other modeled reaches**. For reaches for which RSEI does not calculate water concentrations, EPA assigned background fish tissue concentrations based on the 10th percentile of the distribution of reported concentrations in fish tissue samples in the National Listing Fish Advisory (NLFA) data[88] (see *Table C-1*). EPA found that the distribution of these samples was consistent with values reported in Wathen et al (2014) and used the 10th percentile as representative of background, "clean" reaches not affected by point source discharges.
- **Validating and adjusting the fish tissue concentrations based on empirical data, if needed**. EPA then applied the same method used to validate and adjust estimated fish tissue data in the EA national model to ensure that the fish tissue concentrations calculated based on the RSEI outputs are reasonable when compared to measured data. The approach involves applying order-of-magnitude adjustments in cases where the preliminary concentrations are greater than empirical measurements for a given reach or geographic area by an order of magnitude or more. Section 5.1.2 of the EA describes the methodology in greater detail.

The analysis provides background metal-specific composite fish fillet concentrations for each COMID modeled in RSEI.

Table C-1: Assumed Background Fish Tissue Concentrations, based on 10th percentile

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

D.2 Nutrients and Suspended Sediment

EPA used the USGS's SPARROW model to estimate nutrient and sediment concentrations in receiving and downstream reaches. The calibrated, national models used for this analysis are the same as those used to estimate in-stream concentrations of TN, TP and TSS in the Construction and Development Industry Category ELGs (see U.S. EPA, 2009c). The approach involved the following steps:

- **Referencing the receiving reaches to E2RF1 reaches**. EPA overlaid the medium resolution NHD and E2RF1 features in GIS to develop the crosswalk between the two hydrologic networks.
- **Summing the loads for each E2RF1**. EPA summed the plant-level loadings over each E2RF1 in the baseline and under each of the five regulatory options.
- **Calculating the change in loading for each E2RF1**. EPA calculated the difference between the baseline and post-compliance loadings under each of the five regulatory options.
- **Specifying the change in loading in SPARROW**. The national SPARROW models for nutrients do not have an explicit explanatory variable for point source loadings in mass units. In the TN and TP SPARROW models, point sources (*e.g.*, wastewater treatment plants) are represented by a population variable. The national calibrated models show contributions of 2.2514 kg TN/capita and

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[88] See http://map1.epa.gov/.

0.2319 kg TP/capita for point sources. EPA used these calibrated loading factors to express the load reductions obtained under each of the regulatory options into population-equivalent in SPARROW. This population-equivalent loading was subtracted from the baseline population value for each reach when running the SPARROW model. For the suspended sediment model, EPA used the same approach as used for the C&D ELG analysis, which involved adjusting the mass flux attributed to the urban land explanatory variable in the model to subtract the change in loading achieved under each option, under the assumption that steam electric power plant loadings are implicitly accounted for in the urban land component of the model (see U.S. EPA, 2009c).

The model provides annual average post-compliance concentrations in each E2RF1, which EPA compared with baseline conditions obtained directly from the national, calibrated model.

Appendix E. Details on Modeling of Cardiovascular Disease Incidence and Mortality

E.1 Benefits to Adults from Reduced Lead Exposure

E.1.1 Hazard Reduction under Final ELGs

For each sex, single-year age, and exposure cohort (hereafter cohort), the analysis characterizes two basic survival analyses under the baseline and option scenarios: a death *hazard function* and a *survival function*.[89]

A death *hazard function* (HF), $h(x)$, for an individual surviving to age x years, is a function such that $h(x)dx$ gives the probability of death between ages x and $x + dx$ (where $dx \rightarrow 0$). Specifically, $h(x)dx = P(x < X_d \leq x + dx | X_d > x)$, where X_d is person's exact age at death. The death hazard function is also commonly known as the *hazard rate*, and less commonly as the *force of mortality*. At any point in time, an individual is at risk of death from competing causes, of which cardiovascular disease (CVD) is only one. As discussed in Beyersmann et al. (2009), competing risks can be modeled using cause-specific death hazard functions, which are additive (by the law of total probability):

Equation E-1. $$h(x) = h^{CVD}(x) + h^{OTH}(x)$$

A *survival function*, $S(x)$, is the probability that a person dies at some point after age x, specifically: $S(x) = P(X_d > x)$. The survival function and the hazard function are intrinsically linked, with the survival function determined completely by the hazard function:
$S(x) = \exp\left\{-\int_0^x h(v)dv\right\}$, where *v* represents a time period typically different than *x*.
Thus, to estimate changes in mortality such as those resulting from implementation of the final ELGs, it is necessary to characterize:

(1) baseline CVD death hazard function;

(2) baseline other cause (*i.e.*, non-CVD) death hazard function; and

(3) option-specific CVD death hazard function.

The main source of data for hazard estimation in key simulation elements (1) and (2) above is a life table, which is a collection of statistics that shows age-specific probabilities of survival and fecundity.[90] Employed heavily in actuarial science, demography, population biology, ecology and epidemiology, data from life tables can be used to calculate probabilities of survival to a given age, age-specific life expectancy, population growth rates, and many other demographic characteristics.

The statistics reported in a life table can be used to approximate the (baseline) hazard function. Of a particular interest are the estimates of the initial age-specific mortality rate, q_x: the proportion of people alive at exact age x, who will die before attaining exact age $x + 1$. The initial mortality rate is closely related to the hazard function:

Equation E-2. $$q_x = 1 - S(x+1)/S(x) = 1 - \exp\left\{-\int_x^{x+1} h(v)dv\right\}.$$

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[89] Collett (2003), pp. 10-12.

[90] An extensive discussion of life tables can be found in Shryock et al. (1980) Chapter 15.

Assuming a constant hazard function within each integer age, $\int_x^{x+1} h(v)dv = \int_x^{x+1} h_x dv = h_x$, estimates of the initial age-specific mortality rates q_x reported in the life table can be used to obtain an estimate of the baseline hazard function:

Equation E-3. $h_x^b = \ln\{1 - \widehat{q_x}\}$

At each integer age x, this overall hazard function can be further decomposed into CVD death hazard function and other-cause death hazard function. To this end, annual age-specific CVD death rates (which are reported by the Center for Disease Control and Prevention (CDC) can be used to approximate baseline $q_x^{CVD,b}$ and, consequently, obtain an estimate of the baseline CVD hazard function:

Equation E-4. $h_x^{CVD,b} = \ln\{1 - q_x^{CVD,b}\}$

which is key simulation element (1) noted above.

Additionally, the estimate of the baseline other hazards function can be derived as:

Equation E-5. $h_x^{OTH,b} = h_x^b - h_x^{CVD,b}$

providing key simulation element (2) from above.

EPA used a concentration-response function from a peer reviewed study, Menke et al. (2006). The study finds a multivariate adjusted relative hazards of CVD mortality of 1.53 (1.21-1.94) per 3.4-fold increase in PbB, based on a Cox proportional hazards model using the log of the blood lead level. The corresponding beta estimate (β_{BLL}) for this Hazard Ratio (HR) is 0.35. Cox proportional hazards models, such as the one estimated by Menke et al (2006) are designed to estimate a multiplicative relationship between an outcome (*i.e.*, the CVD death hazard function) and a set of predictors. Menke et al. (2006) assessed the HR in various subgroups, and noted that subgroup interaction terms were not statistically significant, supporting the use of the coefficient for the overall population in benefits estimation. A key assumption of this model, the proportional hazards assumption [met in Menke et al (2006)], is that the HR is constant through time. Based on this information, EPA derived an estimate for β_{BLL} and used it to compute HRs for changes of different magnitudes. EPA calculated HR associated with a known PbB change (due to an ELG regulatory option) as:

Equation E-6. $HR^o = \exp\left\{\beta_{BLL} \cdot \ln\left[\frac{BLL^o}{BLL^b}\right]\right\}$

Hazard functions accounting for reduced CVD mortality following ELG implementation were then calculated as:

Equation E-7. $h_x^{CVD,o} = h_x^{CVD,b} \cdot HR^o$ (eq. 7)

This equation provides key simulation element (3), above.

E.1.2 Estimating Premature Deaths Avoided Over Multiple Years

The value of a statistical life (VSL) is the marginal rate of substitution between wealth and mortality risk in a defined time period, usually taken to be one year. Therefore, the product of VSL and the estimated reduction in risk of premature death represents the affected population’s aggregate willingness to pay (WTP) to reduce its probability of death in one year. EPA estimated the benefits of multi-year mortality risk as the product of:

(1) The reduction in initial age-specific mortality rate (*i.e.*, the proportion of people alive at exact age x, who will die before attaining exact age $x + 1$; commonly represented as q_x) in year t; and

(2) The number of individuals surviving to the beginning of year t. This value is calculated as the initial cohort population size in 2014 multiplied by the probability that these individuals survive to age x [commonly represented as $S(x)$], and are alive at the beginning of year t to enjoy the benefits of the year's mortality risk reduction. EPA used the survival probability under each ELG option (*i.e.*, the survival probability reflecting cumulative reductions in mortality risk prior to year t) in each recursive step of this calculation.

Each pattern of annual mortality rates corresponds to a unique survival curve. Thus, each intervention-related change in mortality rates (over multiple years) will generate a unique change in the cohort's survival curve. *Figure E-1* illustrates such a change for an individual whose baseline initial mortality rate of 0.3 (*i.e.*, a 30 percent chance of death in one year) was reduced to 0.2 (*i.e.*, a 20 percent chance of death in one year) by an intervention which begins in year 0 and continues indefinitely. The baseline survival curve is shown as a solid line, while the dashed line shows the effects of intervention.

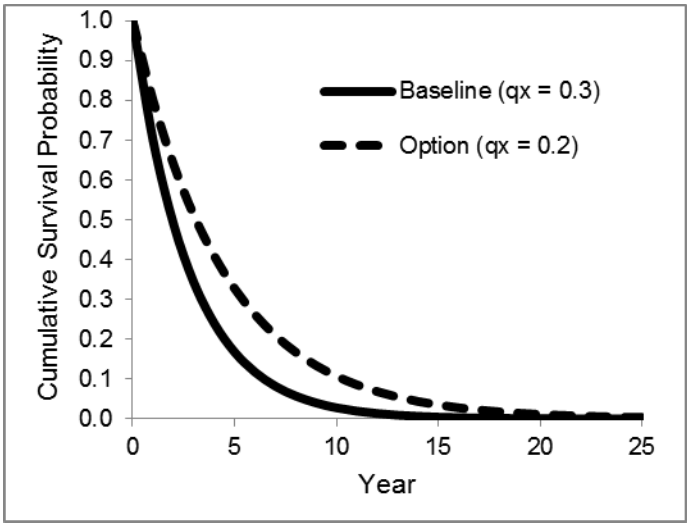

Figure E-1: Illustration of a Hypothetical Policy Effect on a Survival Curve.

Each intervention-related change in survival curve can be summarized by either the gain in life expectancy (*i.e.*, the area between the survival curves) or by the number of avoided premature deaths at each point in time (Hammitt 2007). The recursive calculation of the number of avoided premature deaths (described above) can be seen as a series of shifts of the survival curve. Each shift represents the incremental effect of a mortality risk reduction in year t (while keeping mortality rates in subsequent years at their baseline levels) on the survival curve. Therefore, these shifts are consistent with the cumulative impact of mortality risk reductions in years 0 to $t - 1$. *Figure E-2* illustrates two such shifts: (1) the dashed survival curve reflects the impact of reduced mortality rate in year 0 on the baseline survival curve (*i.e.*, the incremental impact of mortality risk reductions in year 0); (2) the dotted curve reflects the impact of reducing mortality rate in year 1 on the dashed survival curve (*i.e.*, the incremental impact of mortality risk reductions in year 1).

As noted earlier, the area between the survival curves represents the gain in life expectancy. Thus, each shift of the survival curve reflects an incremental gain in life expectancy (*e.g.*, in *Figure E-2*, the area between solid and dashed lines represents the incremental gain in life expectancy because of reduced mortality in year 0; the area between dashed and dotted lines represent incremental gain in life expectancy because of reduced mortality in year 1). By design, the sum of these incremental gains is equal to the original gain in life expectancy from a multi-year reduction. This confirms that EPA's procedure generates an estimated reduction in the risk of premature death that is consistent with the estimated aggregate gain in life expectancy from the final ELGs.

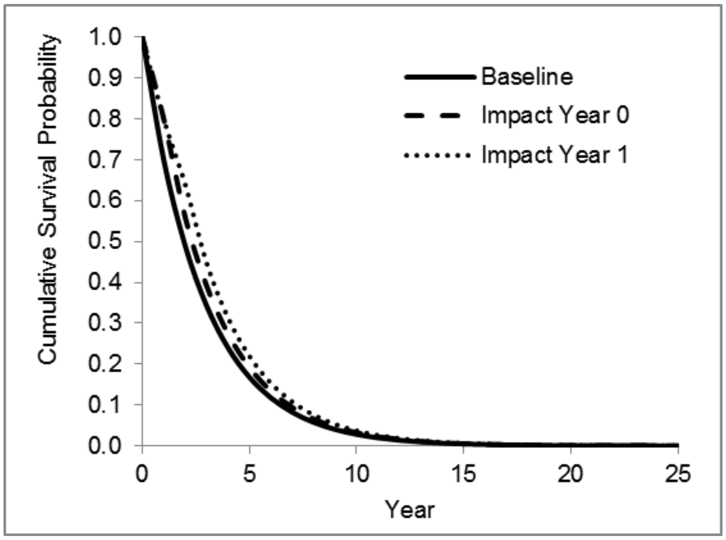

Figure E-2: A Recursive Illustration of a Policy Effect on Survival Rates.

Appendix F. Human Health Benefits Sensitivity Analysis

EPA conducted a series of sensitivity analyses to evaluate the impacts of varying assumptions related to a) the distance travelled by recreational and subsistence anglers, b) the form of the concentration-response function for lead, and c) the cancer slope function and cancer case valuation approach for the arsenic analysis. These analyses are summarized below.

F.1 Alternative Fishing Distance Assumption

The set of reaches that may represent a source of contaminated fish for recreational anglers and subsistence fishers in each CBG depends on the distance the typical angler travels to fish. In the human health benefits analysis (Chapter 3), EPA assumed that anglers typically travel up to 50 miles to fish, using this distance to estimate the relevant fishing sites for the population of anglers in each CBG.

Viscusi et al. (2008) found that 78 percent of anglers live within 100 miles of their fishing destinations. EPA conducted a sensitivity analysis to assess the impact of the travel distance assumptions to the health analysis results. Using a different travel distance assumption tends to increase the number of alternate fishing sites visited by anglers within each CBG, but also increases the availability of substitute sites.

Table F-1 shows the affected population using this alternative fishing travel distance, and *Table F-2* shows the results for the health benefit categories for which EPA conducted this sensitivity analysis.

Table F-1. Summary of Potentially Affected Population Living within 100 Miles of Affected Reaches (baseline)

Total population	306,740,261
Total angler population[a]	42,714,703
Angler population potentially exposed to contaminated fish[b]	29,592,014

a. Total population living within 100 miles of an affected reach times the state-specific share of the population who fishes based on U.S. FWS (2011; between 9% and 23%).

b. Total angler population adjusted to reflect lower fishing/consumption rates for reaches with fish consumption advisories and catch-and-release practices.

Table F-2. Total Monetized Human Health Benefits for ELG Options Using a 100-mile Buffer Zone (millions of 2013$)[a,b]

Regulatory Option	Reduced lead exposure for children		Reduced lead exposure for adults	Reduced mercury exposure for children		Reduced cancer cases from arsenic	Total	
	Low	High		Low	High		Low	High
3% Discount Rate								
Option A	$0.28	$0.40	$3.55	$1.37	$1.92	$0.00	$5.20	$5.87
Option B	$0.28	$0.40	$3.55	$1.39	$1.95	$0.00	$5.22	$5.90
Option C	$0.43	$0.60	$6.66	$2.36	$3.32	$0.00	$9.45	$10.58
Option D	$0.57	$0.80	$8.98	$2.93	$4.11	$0.00	$12.49	$13.90
Option E	$0.57	$0.80	$8.98	$3.30	$4.64	$0.00	$12.86	$14.42

Table F-2. Total Monetized Human Health Benefits for ELG Options Using a 100-mile Buffer Zone (millions of 2013$)[a,b]

Regulatory Option	Reduced lead exposure for children		Reduced lead exposure for adults	Reduced mercury exposure for children		Reduced cancer cases from arsenic	Total	
	Low	High		Low	High		Low	High
7% Discount Rate								
Option A	$0.05	$0.07	$2.96	$0.22	$0.33	$0.00	$3.23	$3.36
Option B	$0.05	$0.07	$2.96	$0.23	$0.33	$0.00	$3.24	$3.37
Option C	$0.07	$0.11	$5.56	$0.38	$0.57	$0.00	$6.01	$6.24
Option D	$0.10	$0.14	$7.50	$0.48	$0.71	$0.00	$8.07	$8.35
Option E	$0.10	$0.14	$7.50	$0.54	$0.80	$0.00	$8.13	$8.44

Source: U.S. EPA Analysis, 2015

a. “-“ indicates that a value was not estimated and “$0.00” indicates that annual benefits are less than $0.01 million.
b. Low bound assumes that the loss of one IQ point results in the loss of 1.76 percent of lifetime earnings (following Schwartz, 1994); high bound assumes that the loss of one IQ point results in the loss of 2.38 percent of lifetime earnings (following Salkever, 1995).

F.2 Log-Linear Concentration Response Function for IQ Impacts to Children from Lead Exposure

In the analysis of benefits to children from reduced lead intake via fish consumption, EPA used a linear concentration-response function to quantify the relationship between blood lead concentrations (PbB) and intelligence quotient (IQ). This linear function is based on a concentration-response function based on children with PbB below 7.5 µg/dL since the average PbB among affected children is approximately 2.7 µg/dL (see Section 3.3). EPA received several comments stating that this approach was inappropriate and resulted in an overestimate of the benefits.

Given the uncertainty surrounding the lead concentration response relationship in children, EPA conducted a sensitivity analysis applying a log-linear function used by EPA (2008b) in the RIA for the Lead National Ambient Air Quality Standards (NAAQS). This function uses a log-linear function for PbB above 1.47 µg/dL and a linear slope for PbB levels below that cut-point, as shown in Equation F-8 and Equation F-9, respectively.

Equation F-8. $$IQ\ Loss = \beta_1 \times \ln\left(\frac{PbB}{cutpoint}\right) + \beta_2 \times cutpoint$$

Equation F-9. $$IQ\ Loss = \beta_2 \times cutpoint$$

Where:

cutpoint = 1.47 µg/dL

β_1 = -3.04 (log-linear regression coefficient)

β_1 = -2.1 (linear regression coefficient)

Table F-3 shows the results of the analysis of avoided IQ point losses among children from exposure to lead using this alternative concentration-response function (corresponding to *Table 3-4* in *Section 3.3*).

Table F-3. Estimated Benefits from Avoided IQ Losses for Children Exposed to Lead using Log-Linear Concentration Response Function (2013$)

Regulatory Option	Average Annual Number of Affected Children 0 to 7	Total Avoided IQ Losses, 2021 to 2042	Annualized Value of Avoided IQ Point Losses[a] (Millions)			
			3% Discount Rate		7% Discount Rate	
			Low Bound	High Bound	Low Bound	High Bound
Option A	3,326,127	324	$0.13	$0.18	$0.02	$0.03
Option B	3,326,127	324	$0.13	$0.18	$0.02	$0.03
Option C	3,326,127	486	$0.19	$0.27	$0.03	$0.05
Option D	3,326,127	816	$0.32	$0.46	$0.05	$0.08
Option E	3,326,127	816	$0.32	$0.46	$0.05	$0.08

Source: U.S. EPA Analysis, 2015

a. Low bound assumes that the loss of one IQ point results in the loss of 1.76% of lifetime earnings (following Schwartz, 1994); high bound assumes that the loss of one IQ point results in the loss of 2.38% of lifetime earnings (following Salkever, 1995).

F.3 Alternative Cancer Slope Factor and Case Valuation for Arsenic Analysis

The Integrated Risk Information System (IRIS) reports a cancer slope factor (CSF) of 1.5 cases per mg/kg BW/day, which is based on incidences of skin cancer. EPA applied the 1.5 cases per mg/kg BW/day CSF to estimate the benefits shown in *Section 3.6.* 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 oral ingestion. The draft CSF is substantially higher – at 25.7 per mg/kg BW/day for women and 16.9 per mg/kg BW/day for men (U.S. EPA, 2010b).

EPA conducted a sensitivity analysis using the more sensitive CSF, together with monetizing the avoided cases using the value of a statistical life (VSL; $8.548 million), reflective of the higher mortality rates associated with internal cancers. *Table F-4* shows the results of this sensitivity analysis (corresponding to *Table 3-12* in *Section 3.6*).

Table F-4. Annual Benefits from Reduced Cancer Cases due to Arsenic Exposure, using Alternative CSF and VSL

Regulatory Option	Annual Affected Population	Reduced Cancer Cases, 2019 to 2042	Benefits (Millions; 2013$)	
			3% Discount	7% Discount
Option A	35,972,005	0.55	$0.13	$0.07
Option B	35,972,005	0.55	$0.13	$0.07
Option C	35,972,005	1.05	$0.25	$0.14
Option D	35,972,005	1.59	$0.38	$0.21
Option E	35,972,005	1.72	$0.41	$0.23

Source: U.S. EPA Analysis, 2015

Appendix G. WQI Regional Subindices

This appendix provides the ecoregion-specific parameters used in estimating the TSS, TN, or TP water quality subindex, as follows:

- If [WQ Parameter] $\leq$ WQ Parameter $_{100}$ Subindex = 100
- If WQ Parameter $_{100}$ < [WQ Parameter] $\leq$ 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 TSS, TN, or TP and WQ Parameter $_{10}$, WQ Parameter $_{100}$, a, and b are specified in Table G-1 for TSS, Table G-2 for TN, and Table G-3 for TP.

Table G-1: TSS Subindex Curve Parameters, by Ecoregion

ID	Ecoregion Name	a	b	TSS_{100}	TSS_{10}
10.1.2	Columbia Plateau	126.56	-0.0038	63	668
10.1.3	Northern Basin and Range	112.42	-0.0007	160	3,457
10.1.4	Wyoming Basin	123.36	-0.001	220	2,513
10.1.5	Central Basin and Range	121.22	-0.0018	109	1,386
10.1.6	Colorado Plateaus	144.44	-0.001	363	2,670
10.1.7	Arizona/New Mexico Plateau	126.76	-0.0004	668	6,349
10.1.8	Snake River Plain	146.39	-0.0027	142	994
10.2.1	Mojave Basin and Range	119.34	-0.0015	121	1,653
10.2.2	Sonoran Desert	112.39	-0.0002	567	12,097
10.2.4	Chihuahuan Desert	214.39	-0.0005	1,419	6,130
11.1.1	California Coastal Sage, Chaparral, and Oak Woodlands	127.97	-0.0012	205	2,124
11.1.2	Central California Valley	171.86	-0.0044	122	646
11.1.3	Southern and Baja California Pine-Oak Mountains	115.12	-0.0007	197	3,491
12.1.1	Madrean Archipelago	261.35	-0.0005	2,053	6,527
13.1.1	Arizona/New Mexico Mountains	120.98	-0.0004	477	6,233
15.4.1	Southern Florida Coastal Plain	116.95	-0.0405	4	61
5.2.1	Northern Lakes and Forests	157.76	-0.0233	20	118
5.2.2	Northern Minnesota Wetlands	154.99	-0.0186	24	147
5.3.1	Northern Appalachian and Atlantic Maritime Highlands	174.99	-0.0261	21	110
5.3.3	North Central Appalachians	245.15	-0.0176	51	182
6.2.10	Middle Rockies	144.64	-0.0038	98	703
6.2.11	Klamath Mountains	238.9	-0.0068	129	467
6.2.12	Sierra Nevada	185.36	-0.0116	53	252
6.2.13	Wasatch and Uinta Mountains	124.28	-0.0014	160	1,800
6.2.14	Southern Rockies	153.42	-0.0031	140	881
6.2.15	Idaho Batholith	184.23	-0.0142	43	205
6.2.3	Columbia Mountains/Northern Rockies	180.7	-0.0168	35	172
6.2.4	Canadian Rockies	396.62	-0.0308	45	119
6.2.5	North Cascades	240.95	-0.0193	46	165
6.2.7	Cascades	192.94	-0.0181	36	164
6.2.8	Eastern Cascades Slopes and Foothills	178.82	-0.0145	40	199
6.2.9	Blue Mountains	148.35	-0.0037	107	729
7.1.7	Strait of Georgia/Puget Lowland	181.06	-0.0224	27	129
7.1.8	Coast Range	174.78	-0.0114	49	251
7.1.9	Willamette Valley	210.3	-0.0114	65	267

Table G-1: TSS Subindex Curve Parameters, by Ecoregion

ID	Ecoregion Name	a	b	TSS_{100}	TSS_{10}
8.1.1	Eastern Great Lakes and Hudson Lowlands	144.62	-0.0104	36	257
8.1.2	Lake Erie Lowland	112.79	-0.0049	25	494
8.1.3	Northern Appalachian Plateau and Uplands	322.68	-0.0113	103	307
8.1.4	North Central Hardwood Forests	148.68	-0.0108	37	250
8.1.5	Driftless Area	117.97	-0.0012	141	2,057
8.1.6	S. Michigan/N. Indiana Drift Plains	191.44	-0.0143	46	206
8.1.7	Northeastern Coastal Zone	158.48	-0.0164	28	168
8.1.8	Maine/New Brunswick Plains and Hills	156.02	-0.025	18	110
8.1.10	Erie Drift Plain	133.08	-0.0037	78	700
8.2.1	Southeastern Wisconsin Till Plains	121.34	-0.0042	46	594
8.2.2	Huron/Erie Lake Plains	145.17	-0.0058	65	461
8.2.3	Central Corn Belt Plains	187.95	-0.0033	191	889
8.2.4	Eastern Corn Belt Plains	235.18	-0.003	282	1,053
8.3.1	Northern Piedmont	175.82	-0.0042	135	683
8.3.2	Interior River Valleys and Hills	149.68	-0.0013	303	2,081
8.3.3	Interior Plateau	220.47	-0.0037	217	836
8.3.4	Piedmont	224.11	-0.0048	169	648
8.3.5	Southeastern Plains	205.3	-0.0085	85	356
8.3.6	Mississippi Valley Loess Plains	492.49	-0.0048	333	812
8.3.7	South Central Plains	184.36	-0.0045	136	648
8.3.8	East Central Texas Plains	162.32	-0.0013	362	2,144
8.4.1	Ridge and Valley	186.83	-0.0063	99	465
8.4.2	Central Appalachians	166.76	-0.0062	82	454
8.4.3	Western Allegheny Plateau	183.67	-0.0032	190	910
8.4.4	Blue Ridge	216.16	-0.0087	89	353
8.4.5	Ozark Highlands	175.16	-0.0018	317	1,591
8.4.6	Boston Mountains	329.77	-0.0062	193	564
8.4.7	Arkansas Valley	283.25	-0.004	261	836
8.4.8	Ouachita Mountains	212.77	-0.0048	157	637
8.4.9	Southwestern Appalachians	207.09	-0.0071	103	427
8.5.1	Middle Atlantic Coastal Plain	182.17	-0.0178	34	163
8.5.2	Mississippi Alluvial Plain	131.35	-0.0029	93	888
8.5.3	Southern Coastal Plain	138.62	-0.0144	23	183
8.5.4	Atlantic Coastal Pine Barrens	283.76	-0.0463	23	72
9.2.1	Aspen Parkland/Northern Glaciated Plains	136.43	-0.0005	640	5,226
9.2.2	Lake Manitoba and Lake Agassiz Plain	174.13	-0.0042	131	680
9.2.3	Western Corn Belt Plains	135.01	-0.0009	347	2,892
9.2.4	Central Irregular Plains	201.19	-0.001	673	3,002
9.3.1	Northwestern Glaciated Plains	133.98	-0.0006	483	4,325
9.3.3	Northwestern Great Plains	130.6	-0.0004	636	6,424
9.3.4	Nebraska Sand Hills	289.85	-0.0066	162	510
9.4.1	High Plains	125.61	-0.0005	507	5,061
9.4.2	Central Great Plains	156.84	-0.0005	925	5,505
9.4.3	Southwestern Tablelands	137.77	-0.0003	1,280	8,743
9.4.4	Flint Hills	270.93	-0.0009	1,084	3,666
9.4.5	Cross Timbers	134.97	-0.0006	523	4,337
9.4.6	Edwards Plateau	173.77	-0.001	544	2,855
9.4.7	Texas Blackland Prairies	134.23	-0.0005	624	5,194

Table G-1: TSS Subindex Curve Parameters, by Ecoregion

ID	Ecoregion Name	a	b	TSS$_{100}$	TSS$_{10}$
9.5.1	Western Gulf Coastal Plain	124.47	-0.0025	88	1,009
9.6.1	Southern Texas Plains/Interior Plains and Hills with Xerophytic Shrub and Oak Forest	166.67	-0.0003	1,602	9,378

Table G-2: TN Subindex Curve Parameters, by Ecoregion

ID	Ecoregion Name	a	b	TN$_{100}$	TN$_{10}$
10.1.2	Columbia Plateau	116.58	-0.663	0.23	3.70
10.1.3	Northern Basin and Range	126.97	-0.626	0.38	4.06
10.1.4	Wyoming Basin	124.89	-0.445	0.50	5.67
10.1.5	Central Basin and Range	116.66	-0.335	0.46	7.33
10.1.6	Colorado Plateaus	146.41	-0.588	0.65	4.56
10.1.7	Arizona/New Mexico Plateau	116.33	-0.286	0.53	8.58
10.1.8	Snake River Plain	129.93	-0.594	0.44	4.32
10.2.1	Mojave Basin and Range	136.69	-0.593	0.53	4.41
10.2.2	Sonoran Desert	117.99	-0.495	0.33	4.99
10.2.4	Chihuahuan Desert	104.2	-0.45	0.09	5.21
11.1.1	California Coastal Sage, Chaparral, and Oak Woodlands	123.22	-0.889	0.23	2.82
11.1.2	Central California Valley	126.07	-0.548	0.42	4.62
11.1.3	Southern and Baja California Pine-Oak Mountains	122.76	-0.564	0.36	4.45
12.1.1	Madrean Archipelago	130.61	-0.325	0.82	7.91
13.1.1	Arizona/New Mexico Mountains	141.64	-0.541	0.64	4.90
15.4.1	Southern Florida Coastal Plain	1000000	-29.36	0.33	0.39
5.2.1	Northern Lakes and Forests	141.98	-0.985	0.36	2.69
5.2.2	Northern Minnesota Wetlands	142.55	-0.781	0.45	3.40
5.3.1	Northern Appalachian and Atlantic Maritime Highlands	142.6	-0.854	0.42	3.11
5.3.3	North Central Appalachians	180.92	-0.897	0.66	3.23
6.2.10	Middle Rockies	136.51	-0.991	0.31	2.64
6.2.11	Klamath Mountains	140.34	-1.805	0.19	1.46
6.2.12	Sierra Nevada	143.02	-1.424	0.25	1.87
6.2.13	Wasatch and Uinta Mountains	129.75	-0.452	0.58	5.67
6.2.14	Southern Rockies	131.07	-0.66	0.41	3.90
6.2.15	Idaho Batholith	149.42	-1.775	0.23	1.52
6.2.3	Columbia Mountains/Northern Rockies	136.14	-1.599	0.19	1.63
6.2.4	Canadian Rockies	151.95	-2.098	0.20	1.30
6.2.5	North Cascades	155.86	-1.231	0.36	2.23
6.2.7	Cascades	143.07	-1.473	0.24	1.81
6.2.8	Eastern Cascades Slopes and Foothills	123.99	-1.07	0.20	2.35
6.2.9	Blue Mountains	125.19	-0.786	0.29	3.22
7.1.7	Strait of Georgia/Puget Lowland	121.09	-0.723	0.26	3.45
7.1.8	Coast Range	136.15	-1.021	0.30	2.56
7.1.9	Willamette Valley	135.01	-0.809	0.37	3.22
8.1.1	Eastern Great Lakes and Hudson Lowlands	158.18	-0.563	0.81	4.90
8.1.2	Lake Erie Lowland	156.27	-0.38	1.18	7.23
8.1.3	Northern Appalachian Plateau and Uplands	431.78	-0.435	3.36	8.66
8.1.4	North Central Hardwood Forests	163.4	-0.599	0.82	4.66
8.1.5	Driftless Area	126.18	-0.272	0.85	9.32
8.1.6	S. Michigan/N. Indiana Drift Plains	130.25	-0.149	1.78	17.23

Table G-2: TN Subindex Curve Parameters, by Ecoregion

ID	Ecoregion Name	a	b	TN_{100}	TN_{10}
8.1.7	Northeastern Coastal Zone	125.75	-0.159	1.44	15.92
8.1.8	Maine/New Brunswick Plains and Hills	139.55	-0.553	0.60	4.77
8.1.10	Erie Drift Plain	148.99	-1.256	0.32	2.15
8.2.1	Southeastern Wisconsin Till Plains	134.85	-0.16	1.87	16.26
8.2.2	Huron/Erie Lake Plains	119.06	-0.091	1.91	27.22
8.2.3	Central Corn Belt Plains	135.57	-0.087	3.50	29.96
8.2.4	Eastern Corn Belt Plains	149.12	-0.122	3.28	22.15
8.3.1	Northern Piedmont	146.34	-0.314	1.21	8.55
8.3.2	Interior River Valleys and Hills	120.48	-0.131	1.43	19.00
8.3.3	Interior Plateau	146.39	-0.446	0.85	6.02
8.3.4	Piedmont	148.67	-0.637	0.62	4.24
8.3.5	Southeastern Plains	138.73	-0.727	0.45	3.62
8.3.6	Mississippi Valley Loess Plains	123.15	-0.379	0.55	6.62
8.3.7	South Central Plains	149.84	-0.706	0.57	3.83
8.3.8	East Central Texas Plains	136	-0.344	0.89	7.59
8.4.1	Ridge and Valley	158.11	-0.659	0.70	4.19
8.4.2	Central Appalachians	161.22	-0.907	0.53	3.07
8.4.3	Western Allegheny Plateau	125.25	-0.44	0.51	5.74
8.4.4	Blue Ridge	158.16	-0.777	0.59	3.55
8.4.5	Ozark Highlands	145.69	-0.513	0.73	5.22
8.4.6	Boston Mountains	168.59	-1.108	0.47	2.55
8.4.7	Arkansas Valley	135.4	-0.47	0.64	5.54
8.4.8	Ouachita Mountains	162.34	-0.942	0.51	2.96
8.4.9	Southwestern Appalachians	143.42	-0.645	0.56	4.13
8.5.1	Middle Atlantic Coastal Plain	123.43	-0.444	0.47	5.66
8.5.2	Mississippi Alluvial Plain	119.57	-0.31	0.58	8.00
8.5.3	Southern Coastal Plain	118.73	-0.701	0.24	3.53
8.5.4	Atlantic Coastal Pine Barrens	110.04	-0.482	0.20	4.98
9.2.1	Aspen Parkland/Northern Glaciated Plains	141.62	-0.086	4.06	30.82
9.2.2	Lake Manitoba and Lake Agassiz Plain	119.49	-0.082	2.18	30.25
9.2.3	Western Corn Belt Plains	129.28	-0.074	3.48	34.59
9.2.4	Central Irregular Plains	142.81	-0.184	1.93	14.45
9.3.1	Northwestern Glaciated Plains	120.91	-0.386	0.49	6.46
9.3.3	Northwestern Great Plains	125.65	-0.404	0.56	6.26
9.3.4	Nebraska Sand Hills	113.81	-0.324	0.40	7.51
9.4.1	High Plains	121.41	-0.161	1.21	15.51
9.4.2	Central Great Plains	129.36	-0.178	1.44	14.38
9.4.3	Southwestern Tablelands	136.03	-0.413	0.74	6.32
9.4.4	Flint Hills	142.74	-0.343	1.04	7.75
9.4.5	Cross Timbers	130.87	-0.278	0.97	9.25
9.4.6	Edwards Plateau	141.98	-0.588	0.60	4.51
9.4.7	Texas Blackland Prairies	133.84	-0.243	1.20	10.68
9.5.1	Western Gulf Coastal Plain	106.22	-0.301	0.20	7.85
9.6.1	Southern Texas Plains/Interior Plains and Hills with Xerophytic Shrub and Oak Forest	102.35	-0.374	0.06	6.22

Table G-3: TP Subindex Curve Parameters, by Ecoregion

ID	Ecoregion Name	a	b	TP_{100}	TP_{10}
10.1.2	Columbia Plateau	147.39	-2.211	0.18	1.22
10.1.3	Northern Basin and Range	165.9	-2.78	0.18	1.01
10.1.4	Wyoming Basin	143.83	-1.57	0.23	1.70
10.1.5	Central Basin and Range	167.24	-2.541	0.20	1.11
10.1.6	Colorado Plateaus	123.74	-0.784	0.27	3.21
10.1.7	Arizona/New Mexico Plateau	168.68	-3.39	0.15	0.83
10.1.8	Snake River Plain	140.75	-1.106	0.31	2.39
10.2.1	Mojave Basin and Range	139.89	-0.978	0.34	2.70
10.2.2	Sonoran Desert	122.92	-1.578	0.13	1.59
10.2.4	Chihuahuan Desert	132.89	-3.737	0.08	0.69
11.1.1	California Coastal Sage, Chaparral, and Oak Woodlands	125.05	-1.918	0.12	1.32
11.1.2	Central California Valley	126.32	-2.138	0.11	1.19
11.1.3	Southern and Baja California Pine-Oak Mountains	212.01	-0.941	0.80	3.25
12.1.1	Madrean Archipelago	140.62	-1.331	0.26	1.99
13.1.1	Arizona/New Mexico Mountains	555.88	-306	0.01	0.01
15.4.1	Southern Florida Coastal Plain	157.9	-26.64	0.02	0.10
5.2.1	Northern Lakes and Forests	152.78	-16.37	0.03	0.17
5.2.2	Northern Minnesota Wetlands	171.4	-21.87	0.02	0.13
5.3.1	Northern Appalachian and Atlantic Maritime Highlands	260.92	-21.53	0.04	0.15
5.3.3	North Central Appalachians	157.84	-6.439	0.07	0.43
6.2.10	Middle Rockies	188.95	-15.04	0.04	0.20
6.2.11	Klamath Mountains	205.2	-19.13	0.04	0.16
6.2.12	Sierra Nevada	142.56	-2.752	0.13	0.97
6.2.13	Wasatch and Uinta Mountains	141.72	-5.463	0.06	0.49
6.2.14	Southern Rockies	185.94	-21.89	0.03	0.13
6.2.15	Idaho Batholith	168.85	-17.88	0.03	0.16
6.2.3	Columbia Mountains/Northern Rockies	197.1	-27.87	0.02	0.11
6.2.4	Canadian Rockies	289.57	-47.06	0.02	0.07
6.2.5	North Cascades	227.85	-26.77	0.03	0.12
6.2.7	Cascades	154.67	-10.55	0.04	0.26
6.2.8	Eastern Cascades Slopes and Foothills	141.59	-3.31	0.11	0.80
6.2.9	Blue Mountains	165.33	-13.83	0.04	0.20
7.1.7	Strait of Georgia/Puget Lowland	185.34	-14.77	0.04	0.20
7.1.8	Coast Range	159.54	-9.053	0.05	0.31
7.1.9	Willamette Valley	148.02	-7.95	0.05	0.34
8.1.1	Eastern Great Lakes and Hudson Lowlands	230.09	-9.614	0.09	0.33
8.1.2	Lake Erie Lowland	3440.2	-8.887	0.40	0.66
8.1.3	Northern Appalachian Plateau and Uplands	317.21	-13.87	0.08	0.25
8.1.4	North Central Hardwood Forests	132.65	-4.905	0.06	0.53
8.1.5	Driftless Area	141.49	-2.261	0.15	1.17
8.1.6	S. Michigan/N. Indiana Drift Plains	184.34	-5.59	0.11	0.52
8.1.7	Northeastern Coastal Zone	174	-9.944	0.06	0.29
8.1.8	Maine/New Brunswick Plains and Hills	174.73	-28.94	0.02	0.10
8.1.10	Erie Drift Plain	151.79	-3.59	0.12	0.76
8.2.1	Southeastern Wisconsin Till Plains	141.21	-1.577	0.22	1.68
8.2.2	Huron/Erie Lake Plains	247.17	-2.666	0.34	1.20
8.2.3	Central Corn Belt Plains	223.41	-3.555	0.23	0.87
8.2.4	Eastern Corn Belt Plains	196	-3.734	0.18	0.80

Table G-3: TP Subindex Curve Parameters, by Ecoregion

ID	Ecoregion Name	a	b	TP_{100}	TP_{10}
8.3.1	Northern Piedmont	160.97	-2.567	0.19	1.08
8.3.2	Interior River Valleys and Hills	156.71	-3.616	0.12	0.76
8.3.3	Interior Plateau	197.72	-5.623	0.12	0.53
8.3.4	Piedmont	223.39	-9.266	0.09	0.34
8.3.5	Southeastern Plains	177.2	-5.69	0.10	0.51
8.3.6	Mississippi Valley Loess Plains	168	-4.659	0.11	0.61
8.3.7	South Central Plains	166.39	-1.677	0.30	1.68
8.3.8	East Central Texas Plains	178.13	-6.407	0.09	0.45
8.4.1	Ridge and Valley	225.67	-16.59	0.05	0.19
8.4.2	Central Appalachians	187.73	-8.367	0.08	0.35
8.4.3	Western Allegheny Plateau	174.12	-10.5	0.05	0.27
8.4.4	Blue Ridge	152.7	-2.889	0.15	0.94
8.4.5	Ozark Highlands	204.88	-7.364	0.10	0.41
8.4.6	Boston Mountains	287.21	-5.786	0.18	0.58
8.4.7	Arkansas Valley	158.46	-6.821	0.07	0.41
8.4.8	Ouachita Mountains	169.72	-7.296	0.07	0.39
8.4.9	Southwestern Appalachians	153.95	-6.816	0.06	0.40
8.5.1	Middle Atlantic Coastal Plain	141.25	-3.807	0.09	0.70
8.5.2	Mississippi Alluvial Plain	144.74	-7.676	0.05	0.35
8.5.3	Southern Coastal Plain	126.84	-8.388	0.03	0.30
8.5.4	Atlantic Coastal Pine Barrens	156.13	-0.69	0.65	3.98
9.2.1	Aspen Parkland/Northern Glaciated Plains	132.19	-1.087	0.26	2.38
9.2.2	Lake Manitoba and Lake Agassiz Plain	197.19	-1.683	0.40	1.77
9.2.3	Western Corn Belt Plains	200.96	-1.994	0.35	1.50
9.2.4	Central Irregular Plains	134.12	-1.646	0.18	1.58
9.3.1	Northwestern Glaciated Plains	143.32	-1.267	0.28	2.10
9.3.3	Northwestern Great Plains	185	-3.788	0.16	0.77
9.3.4	Nebraska Sand Hills	153.07	-0.946	0.45	2.88
9.4.1	High Plains	188.57	-1.178	0.54	2.49
9.4.2	Central Great Plains	139.57	-0.972	0.34	2.71
9.4.3	Southwestern Tablelands	218.92	-2.351	0.33	1.31
9.4.4	Flint Hills	131.7	-0.78	0.35	3.31
9.4.5	Cross Timbers	159.98	-1.384	0.34	2.00
9.4.6	Edwards Plateau	149.63	-1.064	0.38	2.54
9.4.7	Texas Blackland Prairies	127.17	-1.863	0.13	1.36
9.5.1	Western Gulf Coastal Plain	104.21	-0.513	0.08	4.57
9.6.1	Southern Texas Plains/Interior Plains and Hills with Xerophytic Shrub and Oak Forest	147.39	-2.211	0.18	1.22

Appendix H. Development of Meta-Regression Models of Willingness to Pay for Water Quality Improvements

This meta-regression is a revised version of the 2009 meta-regression used in the benefit analysis of the proposed ELGs to estimate the water quality improvement benefits of the proposed rule (U.S. EPA, 2013a). EPA made a number of improvements to the meta-regression model, including updating the set of studies and introducing GIS explanatory variables into the analysis. In particular, the revised meta-model satisfies the adding-up condition, a theoretically desirable property.[91] This condition ensures that if the model were used to estimate willingness to pay (WTP) for the cumulative water quality change resulting from a number of CWA regulations, the benefits estimates would be equal to the sum of benefits from using the model to estimate WTP for water quality changes separately for each rule. EPA used the revised meta-analysis to estimate the sum of use and non-use values for water quality improvements resulting from the final ELGs.

The following sections describe EPA's literature review to identify additional studies, meta-data development and coding, model specification, regression results, and limitations and uncertainties associated with the model.

H.1 Literature review to identify additional studies

EPA used the 2009 meta-data (U.S. EPA, 2013a) as the starting point for the current revisions and conducted a literature review for additional studies to include in the metadata. The Agency followed Stanley et al. (2013)'s guidelines for meta-regression analyses in economics in documenting the literature search including (a) the exact databases and other sources searched, (b) the precise combination of keywords, and (c) date completed. To identify new studies, EPA relied on the following:

- Searches of general literature databases and search engines (EBSCO, Google Scholar, Google). Search keywords were selected to be sufficiently broad so not to miss relevant studies:
    - First terms: (1) water quality, (2) water clarity, (3) nutrient removal/improvement, (4) water quality index/ladder, (5) clean water, (6) water pollution reduction, (7) water habitat improvement, and (8) stream flow.
    - Second terms: (1) willingness to pay, (2) stated preference, (3) contingent valuation, (4) choice experiments, (5) contingent activity, and (6) conjoint analysis
- Searches of online reference and abstract databases (Environmental Valuation Resource Inventory (EVRI), Benefits Use Valuation Database (BUVD), AgEcon Search, RePEc/IDEAs, and the Oregon State University College of Forestry Recreation Use Values Database);
- Visits to webpages of authors and university programs known to publish stated preference studies and/or water quality valuation research;[92]

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[91] If WQI0 < WQI1 < WQI2, then for a WTP function WTP (WQI0, WQI2, Y0) to satisfy the adding-up property, it must meet the condition that WTP(WQI0, WQI1 , Y0) + WTP(WQI1, WQI2 , Y0 - WTP(WQI0, WQI1, Y0)) = WTP(WQI0, WQI2 , Y0) for all possible values of baseline water quality (WQI0), potential future water quality levels (WQI1 and WQI2), and baseline income (Y0).

[92] This included G. Poe (Cornell), J. Bergstrom (University of Georgia), T. Haab (Ohio State), K. Viscusi (Vanderbilt), R. Carson (U.C. San Diego), W. H. Desvousges, J. Whitehead (Appalachian State), K. Boyle (Virginia Tech), R. Rosenberger (Oregon State), J. Loomis (Colorado State), J. Corrigan (Kenyon College), and R.H. von Haefen (North Carolina State).

- Searches of web sites for Resources for the Future and EPA's National Center for Environmental Economics, both known to conduct environmental and resource economics valuation research;
- Searches of key resource economics journals for 2005 to 2013 (Land Economics, Environmental and Resource Economics, Marine Resource Economics, Journal of Environmental Economics and Management, Water Resources Research, and Ecological Economics). EPA focused these journal-specific searches on the recent period of 2005 to 2013 given the likelihood that older studies were captured under the steps above or captured during literature reviews conducted for prior versions of the MRM; and
- Review of bibliographies of other valuation meta-analyses (Van Houtven et al. 2007; Ge et al. 2013; Brander and Brouwer 2011).

Studies identified during the search were screened according to the following criteria prior to inclusion in the metadata to ensure validity, consistency, and applicability. The identification and review of studies was completed and verified by multiple individuals following recommendations of Stanley et al. (2013):

- *Commodity consistency* – Study must value water quality changes affecting ecosystem services provided by waterbodies, including recreational activities (such as fishing, boating, and swimming), aquatic life support and other nonuse values.[93] EPA did not include studies that estimate WTP for improvements in surface waters used primarily for drinking water.
- *Welfare consistency* – The study must use general accepted stated preference approaches and report theoretically comparable Hicksian welfare measures (Boyle et al. 2013).
- *Amenity detail* – As described by Johnston et al. (2005), "the study must provide sufficient information regarding resource, context, and study attributes to warrant inclusion in the meta-data" (p.223).
- *Study location* – The study must be conducted in the U.S.
- *Research methods* – The study must apply research methods that are supported by the literature and that provide WTP estimates consistent with neoclassical welfare theory.
- *Duplicative studies* – Some studies may be released in multiple forms, such as working papers, conference papers, journal articles, and book chapters. We included only the latest version of the study (e.g., journal article) when there are multiple versions. Studies are screened to remove duplicative analysis and analysis that were subsequently revised and published. Multiple values can be included for a study if they address a different component of the study data or estimate values for alternative resource changes.

Table H-1 summarizes studies in the revised metadata after identifying and screening additional studies. In total, the revised metadata includes 51 stated preference studies that estimated total WTP (use plus nonuse) per household for water quality changes in U.S. waterbodies. The studies address various waterbody types including, rivers, lakes, salt ponds/marshes, and estuaries. The fifteen studies added to the metadata during the current revisions are shaded in *Table H-1*. Two of the new papers (Corrigan et al. 2009; Whitehead 2006) replaced unpublished versions of the same studies (Azevedo et al. 2001; Whitehead et al. 2002). The revised metadata excludes two studies by Viscusi et al. (2008) and Carson and Mitchell (1993). Carson and Mitchell (1993) estimate WTP for water quality improvements nation-wide. It is excluded because its national scale

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[93] For example, a study that estimates WTP for recreational fishing improvements due to fish stocking would not be included in the meta-data. However, a study that estimates WTP for recreational fishing improvements due to nutrient reductions would be included in the meta-data, presuming it satisfies all other criteria.

means that the size of the affected resource area is substantially different from other studies in the meta-data, which at most, assess improvements within a region. On the other hand, Viscusi et al. (2008) asked respondents in a national survey to value water quality improvements within 100 miles of their home. To be included in the metadata, a WTP observation must correspond to a specific affected resource or set of resources that can be delineated in GIS. Viscusi et al. (2008) does not fit into EPA's data coding framework because the affected resource varies across the sample, with each respondent asked to think about their own area. The WTP estimates reported by Viscusi et al. (2008) reflect an average across many affected areas, rather than WTP for a specific affected resource. Many studies contribute multiple observations due to in-study variations in factors such as number or type affected waterbodies, magnitude of water quality improvement, sampled market area, and elicitation methods. The inclusion of multiple observations per study is standard in resource valuation metadata (Nelson and Kennedy 2009). In total, the 51 studies provide 140 WTP observations.

Table H-1: Primary Studies in the Metadata[A,B,C,D]

Author(s) and Publication Year	Obs. in Metadata	State(s)	Water Body Type(s)	Willingness to Pay per Household (2007$)		
				Mean	Min.	Max.
Aiken (1985)	1	CO	river and lake	193.18	193.18	193.18
Anderson and Edwards (1986)	1	RI	salt pond/marshes	180.71	180.71	180.71
Banzhaf et al. (2006)	2	NY	Lake	57.47	54.09	60.85
Banzhaf et al. (2011)	1	VA, WV, TN, NC, GA	river/stream	31.30	31.30	31.30
Bockstael et al (1988)	1	DC, MD, VA	Estuary	149.03	149.03	149.03
Bockstael et al. (1989)	2	MD	Estuary	158.30	75.67	240.93
Borisova et al. (2008)	3	WV, VA	river/stream	44.94	18.05	65.82
Cameron and Huppert (1989)	1	CA	Estuary	49.53	49.53	49.53
Carson et al. (1994)	2	CA	estuary	59.40	41.21	77.59
Clonts and Malone (1990)	3	AL	river/stream	103.20	78.31	127.48
Collins and Rosenberger (2007)	1	WV	river/stream	18.19	18.19	18.19
Collins et al. (2009)	7	WV	river/stream	120.52	2.84	217.57
Corrigan et al. (2009)	1	IA	Lake	123.30	123.30	123.30
Croke et al. (1987)	9	IL	river/stream	77.47	61.31	93.68
De Zoysa (1995)	1	OH	river/stream	70.18	70.18	70.18
Desvousges et al. (1987)	12	PA	river/stream	59.19	19.84	137.26
Downstream Strategies (2008)	2	PA	river/stream	12.74	10.70	14.77
Farber and Griner (2000)	6	PA	river/stream	76.16	16.58	148.59
Hayes et al. (1992)	2	RI	estuary	397.44	390.68	404.19
Herriges and Shogren (1996)	2	IA	Lake	134.55	61.71	207.40
Hite (2002)	2	MS	river/stream	60.08	58.24	61.93
Huang et al. (1997)	2	NC	estuary	258.65	255.01	262.29

Table H-1: Primary Studies in the Metadata[A,B,C,D]

Author(s) and Publication Year	Obs. in Metadata	State(s)	Water Body Type(s)	Willingness to Pay per Household (2007$)		
				Mean	Min.	Max.
Irvin et al. (2007)	4	OH	all freshwater	21.67	19.65	23.23
Johnston et al. (1999)	1	RI	river/stream	180.95	180.95	180.95
Kaoru (1993)	1	MA	salt pond/marshes	218.61	218.61	218.61
Lant and Roberts (1990)	3	IA, IL	river/stream	143.93	124.04	154.31
Lant and Tobin (1989)	9	IA, IL	river/stream	55.63	40.58	67.64
Lichtkoppler and Blaine (1999)	1	OH	river and lake	41.93	41.93	41.93
Lindsey (1994)	8	MD	estuary	66.80	33.40	102.20
Lipton (2004)	1	MD	estuary	63.98	63.98	63.98
Londoño Cadavid and Ando (2013)	2	IL	river/stream	38.68	35.93	41.44
Loomis (1996)	1	WA	river/stream	93.07	93.07	93.07
Lyke (1993)	2	WI	river and lake	78.75	59.75	97.74
Matthews et al. (1999)	2	MN	river/stream	21.73	18.14	25.32
Opaluch et al. (1998)	1	NY	estuary	138.47	138.47	138.47
Roberts and Leitch (1997)	1	MN, SD	Lake	8.35	8.35	8.35
Rowe et al. (1985)	1	CO	river/stream	134.59	134.59	134.59
Sanders et al. (1990)	4	CO	river/stream	160.69	81.01	210.04
Schulze et al. (1995)	2	MT	river/stream	20.84	17.34	24.33
Shrestha and Alavalapati (2004)	2	FL	river and lake	156.46	137.97	174.95
Stumborg et al. (2001)	2	WI	Lake	84.29	66.73	101.86
Sutherland and Walsh (1985)	1	MT	river and lake	146.03	146.03	146.03
Takatsuka (2004)	4	TN	river/stream	286.88	181.90	391.85
Wattage (1993)	3	IA	river/stream	53.89	40.24	74.59
Welle (1986)	6	MN	Lake	167.28	109.60	238.42
Welle and Hodgson (2011)	3	MN	Lake	145.10	10.59	285.06
Wey (1990)	2	RI	salt pond/marshes	147.26	63.95	230.58
Whitehead and Groothuis (1992)	3	NC	river/stream	41.01	31.90	53.16
Whitehead (2006)	3	NC	river/stream	187.18	27.52	365.54

Table H-1: Primary Studies in the Metadata[A,B,C,D]

Author(s) and Publication Year	Obs. in Metadata	State(s)	Water Body Type(s)	Willingness to Pay per Household (2007$)		
				Mean	Min.	Max.
Whitehead et al. (1995)	2	NC	estuary	95.44	78.29	112.59
Whittington et al. (1994)	1	TX	estuary	194.72	194.72	194.72

Notes:

(A): Shading indicates studies added since the 2009 meta-analysis.

(B): Journal publications by Corrigan et al. (2009) and Whitehead (2006) replaced staff papers authored by Azevedo et al. (2001) and Whitehead (2002), respectively.

(C): A study by Olsen et al. (1991) from the 2009 meta-analysis was excluded from the current metadata following robustness testing and additional review of study details.

(D): The revised metadata excludes studies by Viscusi et al. (2008) and Carson and Mitchell (1993) that surveyed households across the U.S.

H.2 Variable Development and Coding

EPA entered values for all existing variables in the metadata for each new study identified during the literature review. Next, EPA developed and coded new variables (for all studies) that address gaps in the 2009 metadata. The variables in the revised MRM 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, WTP estimation method, and publication type. These variables are included to explain differences in WTP across studies but are not expected to vary across benefit transfer for different policy applications.

Region and surveyed populations variables characterize such features as the US region 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 water bodies, the size of the market area over which populations were sampled, as well as land cover and the quantity of substitute water bodies.

Water quality (baseline and change) variables characterize baseline conditions and the extent of the water quality change.

Table H-2 presents and defines key variables from the metadata by category. Shading indicates that the variable was developed during these revisions. The development of new variables focused primarily on developing variables that capture geospatial factors including extent of sampled market, surveyed populations and affected resources.[94] The 2009 MRM largely relied on binary variables to distinguish broad categories of affected resources (*e.g.*, single vs multiple rivers, regional freshwater, etc.). Extensive GIS mapping is required in order to quantitatively incorporate new spatial factors using continuous variables because many primary studies give broad outlines but omit the detailed geospatial information regarding affected resources and sampled populations. This type of supplementation has been used by others to include various types of

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[94] EPA also coded one new methodological variable, *ce*, to identify studies that used a choice experiment approach.

information into valuation MRMs other than that necessary for the current metadata (e.g., Ghermandi et al. 2010; Ghermandi and Nunes 2013). By linking to publicly available GIS data layers, EPA provides a consistent basis for the construction and coding of the new, spatial variables. The following subsections describe both development and coding of water quality and spatial variables for surveyed populations, extent of sampled market, study site, and affected resources. In accordance with Stanley et al. (2013) guidelines, all variable coding was reviewed by multiple individuals and documented clearly in the metadata and data dictionary.

Annual WTP values are typically desired for policy analysis to support a comparison of annualized costs and benefits. The metadata includes total WTP as reported by the original study, adjusted to 2007$.[95] For over 80 percent of observations (114 studies), total WTP reflects annual payments in perpetuity (113 studies) and one observation reflects annual WTP for a 10-year payment period. For the remaining 26 observations, WTP reflects a short-term payment period (11 observations use a one-time lump sum payment, 1 observation uses a 3-year payment period, and 14 observations use a 5-year payment period). EPA used the *lump_sum* binary variable to account for short-term payment periods (*lump_sum*=1). EPA also tested models with WTP values for short-term payment periods converted to perpetual streams but found that results were sensitive to discount rate assumptions and that these models did not provide any practical advantages for benefit transfer over models using the *lump_sum* variable.

Table H-2: Definition and Summary Statistics for Model Variables[A]

Variable	Definition	Units	Mean	St. Dev.
	Study Methodology and Year			
Ce	Binary variable indicating that the study is a choice experiment	Binary (Range: 0 or 1)	0.1071	0.3104
Thesis	Binary variable indicating that the study is a thesis.	Binary (Range: 0 or 1)	0.1143	0.3193
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 2011).	2.2127	0.9282
Volunt	Binary variable indicating that WTP was estimated using a payment vehicle described as voluntary as opposed to, for example, property taxes.	Binary (Range: 0 or 1)	0.0857	0.2809
outliers_trim	Binary variable indicating that outlier bids were excluded when estimating WTP.	Binary (Range: 0 or 1)	0.1929	0.3960
nonparam	Binary variable indicating that WTP was estimated using non-parametric methods.	Binary (Range: 0 or 1)	0.4286	0.4966
non_reviewed	Binary variable indicating that the study was not published in a peer-reviewed journal.	Binary (Range: 0 or 1)	0.2357	0.4260
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 (Range: 0 or 1)	0.1857	0.3903

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[95] EPA used $2007 because the a majority of observations were already converted to $2007 as part of the 2009 meta-analysis used ELGs (U.S. EPA, 2013a).

Table H-2: Definition and Summary Statistics for Model Variables[A]

Variable	Definition	Units	Mean	St. Dev.
wtp_median	Binary variable indicating that the WTP measure from the study is the median.	Binary (Range: 0 or 1)	0.0714	0.2585
Region and Surveyed Populations				
northeast	Binary variable indicating that the survey included respondents from states within the Northeast U.S., defined as ME, NH, VT, MA, RI, CT, and NY. This is equivalent to EPA Region 1 plus NY or the Northeast USDA region.	Binary (Range: 0 or 1)	0.0714	0.2585
Central	Binary variable indicating that the survey included respondents from states within the Central U.S., defined as OH, MI, IN, IL, WI, MN, IA, MO, ND, SD, NE, KS, MT, WY, UT, and CO. This is equivalent to EPA regions 5, 7, and 8 or the Midwest and Mountain Plains USDA regions.	Binary (Range: 0 or 1)	0.3643	0.4830
southB,C	Binary variable indicating that the survey included respondents from states within the Southern U.S, defined as NC, SC, GA, FL, KY, TN, MS, AL, AR, LA, OK, TX, and NM. This is equivalent EPA regions 4 and 6, or the Southeast and Southwest USDA regions.	Binary (Range: 0 or 1)	0.1571	0.3652
nonusers	Binary variable indicating that the survey was implemented over a population of recreational nonusers (default category for this variable is a survey of any population that includes both users and nonusers).	Binary (Range: 0 or 1)	0.0857	0.2809
lnincome	Natural log of the median income (in 2007$) for the sample area of each study based on historical U.S. Census data. It was designed to provide a consistent income variable given differences in reporting of respondent income across studies in the metadata (i.e., mean vs. median). Also, some studies do not report respondent income. This variable was estimated for all studies in the metadata regardless of whether the study reported summary statistics for respondent income.	Natural log of income (2007$) (sample area income ranges from $34,332 to $78,444)	10.7453	0.1731
Sampled Market and Affected Resource				
mult_bod	Binary variable indicating that the survey addressed multiple waterbody types. The eight waterbody type categories are (1) river/stream, (2) lake, (3) all freshwater, (4) estuary, (5) wetlands, (6) river and lake, (7) salt pond/marshes, and (8) multiple (estuary and fresh water). Takes on a value of 1 if the study is coded as category (3), (6), or (8).	Binary (Range: 0 or 1)	0.0786	0.2700
River	Binary variable that takes on a value of 1 if the study affects a river, such that river length>0, and zero otherwise.	Binary (Range: 0 or 1)	0.6857	0.4659
swim_use	Binary variable indicating that the affected use(s) stated in the study include swimming.	Binary (Range: 0 or 1)	0.2643	0.4425

Table H-2: Definition and Summary Statistics for Model Variables[A]

Variable	Definition	Units	Mean	St. Dev.
gamefish	Binary variable indicating that the affected use stated in the study is gamefishing.	Binary (Range: 0 or 1)	0.0571	0.2329
boat_use	Binary variable indicating that the affected use(s) stated in the study includes boating.	Binary (Range: 0 or 1)	0.1143	0.3193
ln_ar_agr	Natural log of the proportion of the affected resource area which is agricultural based on 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). EPA also tested a variable for the fraction of lands that is developed land classes, but it did not improve model fit.	Natural log of proportion (Range: 0 to 1)	-1.4329	0.9031
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 (km2/km2)	-1.1278	2.6067
sub_proportion	The proportion of water bodies of the same hydrological type affected by the water quality change, within affected state(s). For rivers, this is measured as the length of the affected river reaches as a proportion of all reaches of the same order. For lakes and ponds, this is defined as the area of the affected water body as a proportion of all water bodies of the same National Hydrography Dataset classification. For bays and estuaries, this is defined as the shoreline length of the water body 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 maximum of separate substitute proportions for rivers, lakes, and estuaries/bays. The affected resource appears in both the numerator and denominator when calculating *sub_proportion*.	Proportion (Range: 0 to 1) (km/km)	0.1880	0.2911
Water Quality Baseline and Change				
lnquality_ch	Natural log of the change in mean water quality (*quality_ch*), specified on the WQI (McClelland 1974; Mitchell and Carson 1989).	WQI units	2.9070	0.6039
Lnbase	Natural log of baseline water quality, specified on the WQI (McClelland 1974; Mitchell and Carson 1989).	WQI units	3.5889	0.6697

Table H-2: Definition and Summary Statistics for Model Variables[A]

Variable	Definition	Units	Mean	St. Dev.

Notes:

(A): Shading indicates that the variable was developed and coded during the current set of revisions.

(B): EPA merged studies from the Southeast and Southwest region into a single group because the metadata includes only one observation from the Southwest region, Whittington et al. (1994) which studied estuaries in Texas

(C): The USDA regions omitted from the regional binary variables are the Mid-Atlantic region (NJ, DE, MD, DC, PA, WV, and VA) and the Western region (WA, OR, ID, CA, NV, AZ, and AK).

H.2.1 Study Methodology and Year

As often found in meta-analyses within the valuation and benefit transfer literature (Navrud and Ready 2007), a variety of study and methodology effects can be shown to influence WTP for water quality improvements. The 2009 metadata included numerous variables characterizing factors including, but not limited to publication type, elicitation method, response rate, treatment of outliers, payment period, and study year. EPA coded values for these variables for the new primary studies following the variable definitions from the 2009 MRM. The majority of the methodological variables in the metadata are binary, with 1 indicating that a given methodology was used in the primary study. Some others, such as study year, are continuous. Most of the methodological variables available in the metadata did not improve model fit and were not included in the revised MRM. Given that choice experiments are being used with increased frequency in the recent literature, EPA coded a new binary variable, *ce*, to flag observations that are based on a choice experiment framework.

H.2.2 Region and Surveyed Populations

The 2009 metadata included variables describing the location of the study by state and region of the country although these were used in a fairly simplistic way in the meta-analysis. EPA expanded the metadata by delineating sampled area for each of the 140 WTP observations as GIS polygons. The sampled area is defined as the geographic area over which the primary survey was fielded (*i.e.*, the population it is meant to be representative of). The Agency based its GIS delineation on the description of the study area from the study documentation and matched to polygon boundaries from publicly available GIS datasets. The sampled area can vary across observations from the same primary study if the WTP values are based on separate survey samples (this is true for 5 of 51).

The sampled areas are typically defined by either jurisdictional boundaries or watershed boundaries:

For sampled areas defined by jurisdictional boundaries (*e.g.*, states, counties, or cities), EPA defined boundaries using the Census Topologically Integrated Geographic Encoding and Referencing (TIGER) state and county shapefiles for 1990, 2000, and 2010. By using the shapefile vintage that most closely corresponds to the year in which the study was fielded, EPA is able to accurately identify boundaries at the time of the study.

For sampled areas defined by watersheds, EPA approximated sampled area boundaries by matching to the U.S. Geologic Survey Hydrologic Unit Code (HUC) Watershed Boundary Dataset (WBD) to approximate the boundaries of the study area.[96] The Agency first matched the watershed polygon in the HUC dataset based on

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[96] The HUC WBD is a package of watershed shapefiles for the contiguous U.S. subdivided to seven levels of resolution. Each resolution level is assigned a specific number of HUC digits, with the number of digits increasing with higher resolutions. The lowest resolution is the HUC 2-digit, or HUC-2, watershed which divide the country into 21 distinct drainage regions. The highest classification is the HUC12 dataset, consisting of

the watershed name presented in the study. If the name could not be matched, EPA consulted the survey materials or maps included in the study to either locate the corresponding HUC watershed or use the materials to trace a watershed polygon manually. If maps are not provided, then EPA used any additional locational information presented in the study to identify a HUC watershed to serve as a proxy for the study watershed. This approach generally involved more interpretation than if the study defined the sampled area based on jurisdictional boundaries (as in previous bullet).[97]

Income is inconsistently reported across primary studies, with some reporting median income, others reporting mean income, and others not reporting any income statistics for the sample. After delineating the sample area for all studies, EPA calculated income statistics for the population within the sampled area using georeferenced historic U.S. Census income data to overcome reporting deficiencies and improve consistency across observations. Historical median income data is available for 1980, 1990, 2000, and 2010. Each sampled area was matched to the data vintage that is nearest to the year in which the study was fielded. EPA derived sampled area income as a population-weighted average of median income across counties that intersect the sampled are polygons. The population weights were adjusted based on the fraction of county area that is within the sample area. Resulting income estimates were adjusted to 2007$ using the Consumer Price Index (CPI).

The 2009 metadata included regional dummies for the study location based on the boundaries of U.S. Department of Agriculture (USDA) regions.[98] The USDA regions were used as the starting point for regional assignments. The boundaries of the seven USDA regions are closely aligned with the ten EPA regions, EPA generated two new binary variables that combine some regions for which effects were found to be similar. Northeast identifies studies that sampled respondents in the Northeast U.S. (as far south as New York, central identifies studies that sampled in the Midwest or Mountain Plains regions of the U.S, and south identifies those that sampled in the Southeast and Southwest U.S. (as far west as New Mexico).[99] The state boundaries for each variable are listed in *Table H-2*.

EPA also calculated the continuous variables *sa_area*, defined as the size of the area sample in square kilometers. *Sa_area* feeds into the index variable, *ln_ar_ratio*, described in detail in the following subsection.

H.2.3 Reconciliation of Water Quality Baseline and Change

An important component metadata development is the reconciliation of variables across observations (Johnston et al. 2005; Smith and Pattanayak 2002; Smith et al. 2002; Van Houtven et al. 2007). Although the calculation and reconciliation of most independent variables requires little explanation, there are some variables for which additional detail is warranted. These include variables characterizing surface water quality and its measurement. To reconcile measures of water quality across studies, EPA adapted the prior approach

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approximately 98,000 watersheds. Additional information about the HUC watershed and delineation process can be found at http://water.usgs.gov/GIS/huc.html.

[97] EPA encourages authors of future studies to describe the sampled area clearly, to avoid the need for judgment or interpretation when including studies in future meta-analyses.

[98] Using ecoregion boundaries to define regional dummies is not feasible because it would result in a very small number of observations per region. Each USDA region includes several ecoregions and thus is better suited for grouping studies.

[99] The default region corresponds to the Mid-Atlantic states (DE, MD, NJ, PA, VA, WV). It also includes the state of California because only two studies (3 observations) correspond to California and because similarly to the Mid-Atlantic states it is a coastal state. No meta-data observations correspond to other states in the Western U.S. (i..e, OR, WA, NV, ID, HI, AZ, AK).

of Johnston et al. (2005) and van Houtven et al. (2007), mapping water quality changes to the 100-point Water Quality Index (WQI).

A large number of the original studies in the metadata (10 studies and 31 percent of observations) include the 10-point water quality ladder (WQL) measures as a native component of the original primary studies either using its numerical values (*e.g.*, 2.5, 5.0, etc.) or descriptive levels (e.g., boatable, gamefishing).[100] In other cases, EPA used descriptive information from studies to map baseline and post-improvement to points on the WQL. To calculate 100-point WQI values EPA multiplied the reported WQL values by ten. In most cases, descriptions correspond closely to levels on WQL, rendering mapping straightforward. EPA used the following guidelines for mapping:

WQL assignments are made based on consideration of information provided in the primary study documentation and, if available, the survey materials. The assignments are not supplemented by external water quality databases or reports. They should reflect the descriptions and metrics presented to respondents within the valuation scenarios.

Identify recreational uses (*e.g.*, boating, fishing, and swimming) provided in the description of baseline and improved (or declined) conditions. These uses may be stated directly or embedded in the definition of water quality metrics (*e.g.*, low, moderate, high) and can include additional descriptive information such as effects on sensitive aquatic species or indication of presence of or amount of specific pollutants.

Only consider those metrics that can be reasonably mapped to the WQL. Ancillary improvements from the improvement plans, such as shoreline trash pickup or terrestrial bird species, are not considered.

Exclude observations that describe an improvement in recreational use that is not tied to a water quality improvement (*e.g.*, an increase in fish abundance not based on water quality improvement).

Start by assigning values corresponding to use thresholds defined on the WQL (*e.g.*, 2.5, 4.5). Assign intermediate values when the changes occur within a specific use category or changes extend beyond the minimum for provision of use. EPA notes that the majority of assignments directly match values corresponding to WQL use thresholds.

To the extent possible, assigned WQL values should reflect the “affected” portion of resource(s) described in the survey, that is, the portion of the resource that is subject to water quality changes under the valuation scenario.

In some cases, uses may be supported intermittently due to algae blooms, for example. If provided, use information regarding the frequency of service provision to calculate intermediate WQL values by weighting use threshold values.

For some types of environmental contamination, such as high acidity, the survey may state that the affected resource supports swimming but has degraded fisheries. It supports a higher use on the WQL (swimming), but not a lower use (gamefishing). . In these cases, we specify baseline WQL and WQL changes based on fishing conditions, the use that is actually improved under the valuation scenario (*e.g.*, a baseline of 4.5 for rough fishing and a post-improvement value of 5.0 for game fishing).

For more detail on water quality description from the original studies and the assigned baseline and improved water quality conditions for each study see Appendix B in *Peer Review Package for Meta-analysis of the Willingness-to-Pay for Water Quality Improvements* (U.S. EPA, 2015e).

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[100] The WQL (Vaughan 1986) is expressed on a scale of 0 to 10 and can be mapped to the WQI by multiplying by 10. Refer to Chapter 10 and Appendix G of the benefits analysis for the C&D Effluent Guidelines (U.S. EPA 2009) for additional detail on the WQI and WQL.

EPA did not identify any systematic variation in results associated with studies for which the WQI was a native component, versus those for which quality changes were mapped to the WQI. A binary variable indicating that the observation used the WQL (*CHNG_WQL*) was not individually significant and did not improve model fit.

H.2.4 Delineation of the Affected Resource and Substitutes

WTP for WQI changes is likely better explained in concert with geospatial factors, given the geographic heterogeneity in the metadata. In the context of water quality valuation, the geospatial scale of a water quality change reflects the area over which the environmental change occurs. EPA expects, all else being equal, that WTP for water quality improvements would be directly related to the size and number of affected waterbodies. EPA defines an affected resource as a waterbody that experience a water quality change under the valuation scenarios presented in the primary study. The number of affected waterbodies assessed in the primary studies varies widely across the metadata from single waterbodies to all waterbodies throughout a state or small region. The existing metadata identifies the geographic scale of the affected resources using four categories: (1) single waterbody, (2) multiple waterbodies, (3) a small region, or (4) a large region. *Table H-3* summarizes the number and percent of observations in each of the four geographic scale categories. As part of the revisions, EPA delineated the affected waterbodies by matching waterbody descriptions and maps from the primary studies to publicly available georeferenced datasets. By delineating resources using GIS, EPA is able to incorporate detailed spatial and hydrological features of the waterbodies. As with sampled area, some primary studies provide separate WTP values for multiple affected resources or sets of affected resources. These are always treated as separate observations within the metadata.

Table H-3: Summary of Scale of Resource Changes in the Meta-data.

Category	Variable	Description	Observation Count	% of Observations
Single Waterbody	*Single*	Single, discrete waterbody such as a river or lake.	49	35.0%
Multiple Waterbodies	*Multi*	Multiple discrete waterbodies (*e.g.*, 2 rivers)	13	9.3%
Small Region	*Sm_reg*	Small region, includes watersheds and state-wide analyses	77	55.0%
Large Region	*Lg_reg*	Large region, includes one estuary analysis that includes multiple states.	1	0.7%
Total	-	-	140	100.0%

The datasets used to map affected resources vary by affected waterbody type. For rivers and lakes, the Agency opted to match to the NHDPlus dataset over other publicly available georeferenced hydrologic datasets (*e.g.*, E2RF1) because it is a comprehensive, national dataset of hydrologic features such as rivers, lakes, ponds and catchments, and contains tabular data that can be linked to these hydrologic features. For estuaries and coastlines, EPA used the National Oceanic and Atmospheric Administration (NOAA) Global Self-Consistent Hierarchical, High-Resolution Geography Database (GSHHD). EPA attempted to match the name of the affected resource to the datasets, and if a match could not be found, used narrative descriptions and maps from the primary study to manually select the affected waterbodies in ArcGIS. Once delineated, EPA calculated affected shoreline length for all waterbody types as proxy for the human/water interface, although some uses actually occur in open water. For rivers, shoreline length is double the reach length to reflect both shorelines. EPA also calculated the area of affected lakes.

Observed mean WTP in a primary study is also related to the extent of market analyzed (Loomis 2000; Loomis and Rosenberger 2006). It is established in economic literature that mean WTP often declines as distance increases to an affected resource (i.e., distance decay) (Bateman et al. 2006; Jørgensen et al. 2013; Schaafsma et al. 2012). Because the scale of the sampled market area varies greatly across primary studies and past work has shown that such differences can have important implications for welfare estimates, the accuracy of benefit transfers depends on the ability to adjust for the distance between affected populations and the resource (Bateman et al. 2006; Johnston and Duke 2009; Johnston and Ramachandran 2013; Loomis and Rosenberger 2006). The size of the sampled area (*sa_area*) in the metadata varies greatly across the metadata mean of 49,065 mi^2 with 5th and 95th percentiles of 13.3 and 104,094 mi2, respectively. *Sa_area* is not correlated with the size of the affected resource because various factors affect researcher's choice of survey region including budget and resource constraints and study objectives. As a result, the metadata does not provide clear information regarding the extent of the market for the affected resources or distance effects.

Modeling results indicated that model performance was enhanced, in terms of model fit, variable significance, and consistency with theoretical expectations, when resource size was specified as a function of sampled market area (*sa_area*). The *ln_ar_ratio* variable reflects the size of the sampled market relative to the size of the affected resource, defined as the (natural log of the) size of the sampled market area (*sa_area*) divided by the geographic area encompassing the affected waters in square kilometers (*ar_total_area*). *Ar_total_area* is calculated based on the area of counties that insect the affected resource. For example, if a study valued all freshwater in Iowa, then *ar_total_area* would equal the area of Iowa. On other hand, *ar_total_area* would equal the area of a single Iowa county if the affected resource falls entirely within the county boundary. The area ratio, *ln_ar_ratio*, is expected to have negative sign reflecting two effects. First, holding all else constant, stated preference surveys over larger market areas imply greater distances between individual households and affected waterbodies, and thus lower WTP per household. Secondly, improvements to more waters within the sampled area should be associated with greater WTP, ceteris paribus.

About 55 percent of observations in the metadata estimated WTP for water quality changes in a single watershed, group of watersheds, or a state. The other 45 percent focused on a single waterbody or small set of waterbodies (*e.g.*, one lake or 3 lakes). Specifying the affected resource area requires some assumptions if the affected resource is defined as a river or lake (*e.g.*, EPA assumed that counties intersecting the affected water bodies represent the affected resource area). As noted above, EPA used intersecting counties to define all affected resources, including discrete rivers, as geographic areas while avoiding the arbitrary selection of a boundary distance.

Relative to the alternatives, *ln_ar_ratio* provides a more intuitive means to capture the scale of the affected resource occurring throughout an area, such as watershed or region which is likely to be the case in the context of national rulemakings. Model fit decreases when the affected area ratio is included in non-logged form and the variable (*ar_ratio*) is no longer individually significant. Logging the ratio is also intuitive because WTP is zero when the resource size is zero. EPA considered, but did not select, a variety of alternative specifications of the geographic scale and extent of market variables (*e.g.*, shoreline length).

The availability and quality of substitutes in the surrounding geographic area are also expected to influence welfare estimates (Loomis and Rosenberger 2006; Schaafsma et al. 2012). All else equal, WTP should be negatively related to substitute availability. EPA developed a continuous variable, *sub_proportion*, defined as the ratio of affected waterbodies to available use and nonuse substitutes within the state. EPA expects that the relationship between distance and substitutes will differ for resource users and nonusers. For users, there is "a positive cost of access which depends on distance" (Hanley et al. 2003, p.300), therefore, sites that are farther away will generally be less attractive substitutes all other things being equal. On the other hand, "there seems no theoretical reason to expect such a [distance decay] trend to be seen within the responses of those who are present non-users" (Bateman et al. 2006, p. 453). There is some evidence that a sense of spatial and cultural identity or "ownership" may be important for nonuse values for some environmental resources (Bateman et al. 2006; Hanley et al. 2003). Hanley et al. (2003) provides the example that "I may have stronger non-use values for Scottish wildlife sites if I am Scottish than for English wildlife sites" (p.300). In the U.S., this may be manifested as affiliation with one's state of residence. Given these factors, EPA considers the state to be a reasonable basis for the calculating the substitute proportion.

The substitute proportion variable (*sub_proportion*) represents a potential advance over less sophisticated binary variables traditionally used to represent the size or scope of affected resources. For studies restricted to rivers, the calculation of substitutes is restricted to rivers of the same stream order(s) as the affected resource to ensure comparability. For non-river inland waterbodies (*e.g.*, lakes and ponds), substitute proportion is calculated based on area relative to area of lakes within the state(s).101 For estuaries and coasts, EPA calculated the denominator as all coastline miles in the state(s). EPA also tested models with separate substitute variables for each waterbody type, but model performance was not improved.

By delineating an affected area, in addition to the waterbodies themselves, EPA is also able to analyze the development characteristics of areas bordering the waterbodies. In particular, EPA estimated the fraction of the land in the study area used for agriculture (*ln_ar_agr*). EPA used the National Land Cover Dataset (NLCD) to develop a land cover profile of the affected resource area. The NLCD is a high-resolution (30 meter) spatial dataset of land cover across the contiguous U.S. and available for the years 1992, 2001 and 2006. The NLCD has 16 or 21 categories of land cover depending on the year. For the purpose of consistency and simplicity, EPA defined the agricultural land as the sum of "cultivated cropland" and "pasture/hay". The Agency used the change in agricultural land between NLCD vintages to interpolate values for the actual year of the study. The agricultural fraction is calculated as the area-weighted average of counties within the affected resource area. Areas dominated by agricultural land uses have particular characteristics which suggest that WTP for water quality improvements could be lower than other types of areas, ceteris paribus:

- First, unlike non-agricultural rural areas, heavily agricultural areas have generally been altered from their natural ecosystem conditions, and do not tend to be highly prized for water-based recreation (or characterized as pristine natural areas) – this would be expected to decrease WTP for improvements in agricultural areas compared to many other rural areas.
- Second, unlike more heavily populated suburban or urban areas, agricultural lands do not have the population base to support well-developed and used recreational areas. Improvements to water bodies in suburban areas, for example, are often highly valued because these areas support extensive recreational and other uses.
- Third, a greater proportion of the population in agricultural areas has employment linked to farm activities that may be associated directly or indirectly with water pollution. Those whose employment depends on farming activities may be hesitant to support programs to improve water quality (in stated preference surveys or otherwise), for fear that these policies may lead to greater restrictions on farms and farming activities.

For all of these reasons, one would expect areas dominated by agriculture to have lower WTP to improve water quality, again holding all else constant. This intuition is strongly supported by model results, as discussed below. EPA also developed and tested an analogous variable based on the fraction of land that is in developed land use categories but it not improve model fit.

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[101] NHDPlus does not provide widths of river and streams.

H.3 Model Specification

EPA tested a number of meta-regression models based on WTP estimates for improvements in water resources, derived from 51 original studies. However, only the marginal WTP model ("Model 1") and its variant ("Model 2") are used in the analysis of benefits of the final ELG because these models satisfy adding-up conditions (Diamond 1996). Model specification for the marginal WTP model, results, and interpretation of the results are described in the following sections. EPA's Peer Review Package for Meta-analysis of the Willingness-to-Pay for Water Quality Improvements (U.S. EPA, 2015e) and memorandum entitled Accounting for Scope in the MRM2 Meta-Regression Model (Abt Associates 2015) provide additional detail on model selection, testing and alternative specifications.[102]

H.3.1 Marginal Willingness to Pay (Model 1)

In the meta-regression model, marginal willingness-to-pay from observation i, $MWTP_i \equiv \frac{\partial WTP_i}{\partial \mathrm{Q}}$, is modeled as follows:

$$\ln(MWTP_i) = \alpha_0 + \boldsymbol{\alpha_1 X_i} + f(Q_i; \boldsymbol{\beta}) + \epsilon_i \qquad (1)$$

In this equation, α_0 is a constant, $\boldsymbol{X_i}$ is a vector of study and resource characteristics that act as demand shifters, Q_i is the absolute water quality index level at which marginal willingness-to-pay is being evaluated, and ϵ_i is a zero-mean normally-distributed error term. The function $f(\cdot)$ expresses the core relationship between absolute water quality Q_i and the log of marginal WTP, and $\boldsymbol{\beta}$ is a vector of parameters that define the functional form of $f(\cdot)$. If $f(\cdot)$ is assumed to be linear in Q_i:

$$f(Q_i; \boldsymbol{\beta}) \equiv \beta \cdot Q_i \qquad (2)$$

then marginal WTP can be expressed as follows:

$$\ln(MWTP_i) = \alpha_0 + \boldsymbol{\alpha_1 X_i} + \beta \cdot Q_i + \epsilon_i \qquad (3)$$

However, $MWTP_i$ is not observed directly in the meta-data, and instead must be calculated from total willingness-to-pay as part of the estimation routine. This would require a nonlinear least squares or maximum likelihood estimation approach. As a simpler alternative, EPA assumed that marginal WTP can be approximated by average WTP per unit of water quality:

$$MWTP_i \approx \frac{WTP_i}{\Delta Q_i} \qquad (4)$$

with this approximation assumed to be valid at some point between Q_{i0} and Q_{i1}, here approximated by the midpoint of the water quality change valued for that meta-data observation:

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[102] Note that Model 1 here is the model referred to as MRM2 in the Peer Review Package, while Model 2 here is the model referred to as MRM2-S in the Accounting for Scope memorandum.

$$Q_i = \frac{Q_{i0}+Q_{i1}}{2} \tag{5}$$

Substituting Equations (4) and (5) into Equation (3) provides the version of the marginal WTP model that is ultimately used as a regression model (Model 1):

$$\ln\left(\frac{WTP_i}{\Delta Q_i}\right) = \alpha_0 + \boldsymbol{\alpha_1 X_i} + \beta \cdot \left(\frac{Q_{i0}+Q_{i1}}{2}\right) + \epsilon_i \tag{6}$$

The simplest version of this regression uses an unweighted OLS approach to generate a vector of estimated parameter values $(\hat{\alpha}_0, \boldsymbol{\hat{\alpha}_1}, \hat{\beta}, \hat{\sigma}^2)$, where $\hat{\sigma}^2$ is the sum of squared residuals divided by N-K, where N is the number of observations and K is the number of parameters. Model 1 then substitutes these estimated values into Equation (3) above, to get an expression that can be used to predict the log of marginal WTP:

$$\ln(MWTP_i) = \hat{\alpha}_0 + \boldsymbol{\hat{\alpha}_1 X_i} + \hat{\beta} \cdot Q_i + \epsilon_i \tag{7}$$

Taking the exponent of both sides produces the following expression for marginal WTP evaluated for a particular set of study and resource characteristics $\boldsymbol{X}$ and a particular water quality index level Q:

$$MWTP = \exp(\hat{\alpha}_0 + \boldsymbol{\hat{\alpha}_1 X} + \hat{\sigma}^2/2) \cdot \exp\left(\hat{\beta} \cdot Q\right) \tag{8}$$

Small changes in water quality (e.g., less than one unit) could be valued using an approximation that involves multiplying predicted MWTP from equation (8) by the amount of the water quality change. Larger water quality changes must account for the curvature of the marginal WTP function, and so must be calculated using the integral:

$$WTP = \int_{Q=Q_0}^{Q_1} \exp(\hat{\alpha}_0 + \boldsymbol{\hat{\alpha}_1 X} + \hat{\sigma}^2/2) \cdot \exp\left(\hat{\beta} \cdot Q\right) dQ \tag{9}$$

which is equal to:

$$WTP = \exp(\hat{\alpha}_0 + \boldsymbol{\hat{\alpha}_1 X} + \hat{\sigma}^2/2) \cdot \frac{\exp(\hat{\beta} \cdot Q_1) - \exp(\hat{\beta} \cdot Q_0)}{\hat{\beta}} \tag{10}$$

Because 98 percent of reach miles affected by the final ELG would experience WQI changes that range between 0 and 1 EPA estimated WTP for water quality improvements by multiplying *MWTP* by the amount of water quality changes expected from the final ELG, as described in *Chapter 4*.

H.3.2 Marginal Willingness to Pay (Model 2)

A key feature of Model 1, as described in Equation (1) above, is that marginal WTP does not depend on the magnitude of the water quality change being valued. In other words, the model assumes that marginal WTP for the one-unit change from 49 to 50 on the water quality index is the same, regardless of whether survey respondents live in an area where baseline water quality is 35 or 49, and whether the expected total water quality change is 30 points or 2 points, respectively.

The meta-data, however, do show a relationship between marginal WTP and the water quality change. This relationship could occur for any number of reasons, including the transformations associated with studies that did not use the WQI or WQL directly, or an omitted variable that is correlated with the water quality improvement. More specifically, the meta-data show that survey respondents express high marginal WTP for modest improvements in water quality, but then express much lower marginal willingness to pay for additional improvements. For more detail see a memorandum entitled Accounting for Scope in the MRM2 Meta-Regression Model (Abt Associates 2015).

To address this relationship in the meta-data while satisfying the adding up condition, EPA developed a variant of the marginal WTP model that includes water quality change as a study methodological characteristic. Similar to other methodological parameters (e.g., the use of a choice experiment format, or a lump sum payment), the water quality change parameter could be set to any appropriate value when the meta-model is used for benefit transfer. Importantly, because water quality change would be treated as a methodological characteristic instead of as a scenario characteristic, the value assigned to the water quality change parameter need not correspond to the specific water quality change being valued in the benefit transfer application. For the same reason, the resulting model will still satisfy the adding-up property.

The following equation presents an expanded version of marginal WTP that allows the water quality change ΔQ_i to enter as a methodological characteristic (hereafter Model 2):

$$\ln(MWTP_i) = \alpha_0 + \boldsymbol{\alpha_1 X_i} + g(\Delta Q_i; \boldsymbol{\phi}) + f(Q_i; \boldsymbol{\beta}) + \epsilon_i \qquad (11)$$

In this equation, ΔQ_i is the magnitude of the water quality change for meta-data observation i, and $\boldsymbol{\phi}$ is a vector of parameters that specify the functional form for the function $g(\cdot)$. For simplicity, EPA modeled the function $g(\cdot)$ as a linear function of the water quality change:

$$g(\Delta Q_i; \boldsymbol{\phi}) \equiv \phi \cdot \Delta Q_i \qquad (12)$$

Substituting Equations (4), (5), and (12) into Equation (11) gives the following regression model:

$$\ln\left(\frac{WTP_i}{\Delta Q_i}\right) = \alpha_0 + \boldsymbol{\alpha_1 X_i} + \phi \cdot \Delta Q_i + \beta \cdot \left(\frac{Q_{i0}+Q_{i1}}{2}\right) + \epsilon_i \qquad (13)$$

The estimated parameters from this equation can be used to generate an expression for both marginal WTP and total WTP:

$$MWTP = \exp(\hat{\alpha}_0 + \boldsymbol{\hat{\alpha}_1 X} + \phi \cdot \Delta Q + \hat{\sigma}^2/2) \cdot \exp(\hat{\beta} \cdot Q) \qquad (14)$$

$$WTP = \exp(\hat{\alpha}_0 + \boldsymbol{\hat{\alpha}_1 X} + \phi \cdot \Delta Q + \hat{\sigma}^2/2) \cdot \frac{\exp(\hat{\beta} \cdot Q_1) - \exp(\hat{\beta} \cdot Q_0)}{\hat{\beta}} \qquad (15)$$

Because ΔQ is treated as a study methodological characteristic, not as a characteristic of the benefit transfer water quality improvement scenario, the parameter ΔQ need not be set equal to $Q_1 - Q_0$ in equations (14) and (15).

H.4 Regression Results

Table H-4 presents regression results for Model 1 and Model 2. The models presented in *Table H-4* were selected after the estimation of numerous preliminary models with different specifications and groups of independent variables. The selection was based on both statistical fit and correspondence with theoretical expectations. EPA estimated the models using robust standard errors to account for study-level dependencies. Measures of fit for the illustrated models are good (R^2 = 0.641 and 0.773). These compare favorably to prior meta-analyses in the published literature.

The model performs well, with intuitive results for virtually all statistically significant variables. The model identifies numerous statistically significant coefficients for variables characterizing (1) study methodology, (2) region and surveyed populations, (3) extent of the market, study site, and affected resources, and 4) water quality. In total in Model 1, 15 out of 23 non-intercept coefficient estimates are statistically significant at $p<0.05$, and 12 of 23 are significant at $p<0.01$. The *sub_proportion* geospatial variable is significant at $p<0.01$ with signs on coefficients that are consistent with expectations.

Given the trans-log functional form, these results for *ln_ar_ratio* imply diminishing marginal returns to scale (*e.g.*, WTP per unit of water quality improvement declines as the scope of water quality change increases). Marginal WTP is lower among studies surveying only nonusers (nonusers), another expected result, because users may hold both use and nonuse values, while nonusers hold only nonuse values, by definition. Methodological variables also show expected patterns. For example, households are willing to pay a greater nominal amount in a one-shot payment (*lump_sum*) than they would be willing to pay in repeated annual payments.[103] Marginal WTP also varies according to the type of uses potentially affected by the proposed changes (particularly *boat_use*). In some cases, these variables may be correlated with water quality condition. However, counterexamples exist: for example, waters may be swimmable but the study focuses on improvements in game fishing (e.g., Banzhaf et al., 2006). EPA found that model fit was better with *swim_use*, *boat_use*, and gamefish included.[104] Thus, dropping these variables could result in omitted variable bias.

As expected, *sub_proportion* has a positive coefficient, indicating that WTP increases as the affected resource constitutes a larger fraction of available substitutes. The coefficient for *ln_ar_ratio* is negative because the sampled area (*sa_area*) is in the numerator indicating that marginal WTP decreases as the sampled market area increases relative to the affected resource. This is consistent with the expectation that a larger sample area will include a greater proportion of respondents who are resource nonusers, who are less familiar with the resource, and/or who live at a greater distance from the affected waters.

A negative coefficient on the agricultural area variable (*ln_ar_agr*) suggests that areas dominated by agriculture have lower WTP to improve water quality, holding all else constant. Because areas dominated by agriculture may be significantly different in terms of both resource and population characteristics, as discussed in the preceding section, this result is not surprising. EPA also notes that removing this variable causes substantial changes elsewhere in the model, a sign that removing this variable could cause non-trivial omitted variables bias.[105]

The absolute water quality variable (*Qavg2*) shows that water quality has a larger effect on marginal WTP under Model 1, compared to Model 2. The coefficient is -0.017 under Model 1 and -0.004 under Model 2.

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[103] As discussed in Section 3, EPA also tested models with WTP values for short-term payment periods converted to perpetual streams but found that results were sensitive to discount rate assumptions and that these models did not provide any practical advantages for benefit transfer over models including the *lump_sum* variable.

[104] Peer Review Package for Meta-analysis of the Willingness-to-Pay for Water Quality Improvements (U.S. EPA, 2015e)

[105] EPA notes that some peer reviewers questioned inclusion of this variable in response to the peer review (U.S. EPA, 2015e). In this analysis, the Agency followed the econometric guidance suggesting that if the inclusion of a variable within a model is questionable, the default solution should be to include the variable (including an irrelevant variable only reduces efficiency; omitting a relevant variable creates bias).

This pattern suggests that after accounting for the change in water quality, absolute water quality may have less of an effect on marginal WTP. However, EPA notes that a t-test would fail to reject the hypothesis that these coefficients are equal.

Model 2 also includes a water quality change variable: *lnquality_ch*. This variable is negative and highly significant. This pattern indicates that marginal WTP is decreasing in the size of the water quality change being valued. This is consistent with the patterns from the raw meta-data, as discussed in detail in a memorandum entitled Accounting for Scope in the MRM2 Meta-Regression Model (Abt Associates 2015).

Overall, a comparison of the R^2 values from the two models indicates Model 2 has greater explanatory power than Model 1. Model 1has a R^2 value of 0.641. In contrast, the R^2 value for Model 2 is 0.773. Given that Model 1 already has 23 variables and a constant, this substantial increase in R^2 from one additional variable suggests that log water quality change is an important variable to include in the model.

Table H-4: Regression Results

Parameter	Model 1		Model 2	
	Parameter Estimate	**Robust Standard Error**	**Parameter Estimate**	**Robust Standard Error**
ce	0.3772	0.3241	0.4233*	0.1991
thesis	0.8664**	0.2721	0.7735**	0.1828
lnyear	-0.4115**	0.1308	-0.5000**	0.0911
volunt	-1.3915**	0.2405	-1.1837**	0.2040
OUTLIER_BIDS	-0.3673	0.2025	-0.2912*	0.1238
nonparam	-0.4076**	0.1215	-0.3902**	0.1322
non_reviewed	-0.7094**	0.2008	-0.8708**	0.1536
lump_sum	0.8427**	0.1895	0.7732**	0.1338
WTP_median	-0.1612	0.3333	-0.1507	0.1800
northeast	1.1785**	0.3389	0.5932*	0.2366
central	0.5607*	0.2154	0.7262**	0.1616
south	1.4028**	0.2361	1.5625**	0.1698
nonusers	-0.5858**	0.1466	-0.5403**	0.1133
lnincome1	0.3327	0.4756	0.9595**	0.3570
mult_bod	-0.8273**	0.2124	-0.6300**	0.1797
river1	-0.0789	0.1748	-0.1738	0.1194
swim_use	-0.2342	0.1781	-0.2697*	0.1223
gamefish	0.2331	0.3894	-0.0103	0.2454
boat_use	-0.7251**	0.2389	-0.3204	0.1715
ln_ar_agr	-0.2713*	0.1106	-0.4134**	0.0875
ln_ar_ratio1	-0.0340	0.0350	-0.0573	0.0292
sub_proportion	1.0983**	0.2738	0.6066**	0.2003
Qavg2	-0.0147*	0.0063	-0.0041	0.0050
lnquality_ch			-0.7456**	0.0947
_cons	-1.0388	5.3335	-6.1401	3.9505
Observations:	140		140	
R^2	0.641		0.773	

Table H-4: Regression Results

Parameter	Model 1		Model 2	
	Parameter Estimate	Robust Standard Error	Parameter Estimate	Robust Standard Error
Weights	Yes		Yes	
Random Effects:	No		No	

Notes: * denotes p<.05; ** denotes p<.01. All standard errors are clustered by study.

Application of Model 2 to estimating benefits of improved water quality resulting from the final ELG requires selection of an appropriate value for the water quality change parameter. There are several potential hypotheses that could explain why survey respondents' implied marginal WTP appears to depend on the overall magnitude of the change in water quality conditions.[106] Overall, the meta-data do not provide any simple way of testing or ruling out these different possibilities. This makes choosing a single value for the water quality change parameter in Model 2 difficult. Therefore, EPA conducted a sensitivity analysis, using the range of water quality change scenarios found in the meta-dataset (*e.g.*, water quality change equal to +5 units and +50 units). This analysis characterizes the range of values that would be generated if EPA were to conduct a well-designed stated preference survey to elicit marginal WTP for the types of water quality improvements expected under the final ELG and future CWA regulations. Note that a water quality improvement of +5 is closer to the levels of water quality improvement in the benefits transfer application here.

H.5 Limitations and Uncertainty

The validity and reliability of benefit transfer—including that based on meta-analysis—depends on a variety of factors. While benefit transfer can provide valid measures of use and nonuse benefits, tests of its performance have provided mixed results (*e.g.*, Desvousges et al. 1998; Vandenberg et al. 2001; Smith et al. 2002; Shrestha et al. 2007). Nonetheless, benefit transfers are increasingly applied as a core component of benefit cost analyses conducted by EPA and other government agencies (Bergstrom and De Civita 1999; Rosenberger and Phipps 2007). Moreover, Smith et al. (2002, p. 134) argue that "nearly all benefit cost analyses rely on benefit transfers, whether they acknowledge it or not." Given the increasing [or as Smith et al. (2002) might argue, universal] use of benefit transfers, an increasing focus is on the empirical properties of applied transfer methods and models.

Although the statistical performance of the models is good, EPA notes several limitations applicable to both Model 1 and Model 2. These limitations stem largely from information available from the original studies, as well as degrees of freedom and statistical significance. An important factor in any benefit transfer is the ability of the study site or estimated valuation equation to approximate the resource and context under which benefit estimates are desired. As is common, the meta-analysis model presented here provides a close but not perfect match to the context in which values are desired. Although all of the studies used in the meta-analysis valued changes in water quality improvements, many studies did not specify the cause of water quality impairment in the baseline or focused on causes that are different from the pollutant of concern in the regulation (*i.e.*, heavy metals and nutrients). Preliminary models, however, suggest no systematic patterns in WTP associated with such factors, at least in the present meta-data.

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[106] Accounting for Scope in the MRM2 Meta-Regression Model (Abt Associates 2015).

Additional limitations relate to the paucity of demographic variables available for inclusion in the model. The only demographic variable incorporated in the analysis (*lnincome1*) was not statistically significant. Other demographic variables are unavailable.

The estimated model produces statistically significant coefficients and allows estimation of WTP based on study and site characteristics. However, strictly speaking, model findings are relative to the specific case studies considered, and must be viewed within the context of the 140-observation data set, with all the appropriate caveats. Although this represents a fairly standard-to-large sample size for a meta-analysis in this context (the 51 studies in the analysis gather data from tens of thousands of respondents), it is relatively small relative to other statistical applications in resource and environmental economics. Model results are also subject to choices regarding functional form and statistical approach, although many of the primary model effects are robust to reasonable changes in functional form and/or statistical methods. The rationale for the specific functional form chosen here is detailed above.

As in all cases, results of the meta-analysis are dependent on the sample of studies available for the given resource change (Navrud and Ready 2007), and may be subject to various selection biases if the available literature does not provide a representative, unbiased perspective on welfare estimates associated with resource changes (Rosenberger and Johnston 2007). In this case, however, the Agency took various steps to ameliorate such potential biases, including the incorporation of both peer-reviewed and gray literature to avoid possible publication biases (Rosenberger and Johnston 2007), and the use of a comprehensive literature review in the attempt to avoid—as much as possible—other types of selection biases.

Appendix I. Impacts of Steam Electric Pollutants on Aquatic Species

Table I-1: Common Coal-combustion Wastewater Pollutants (adapted from EPA, 2009d)

Compound	Potential Environmental Concern
Arsenic	Frequently observed in high concentrations in coal combustion wastewater; causes poisoning of the liver in fish and developmental abnormalities; is associated with an increased risk of cancer in humans in the liver and bladder.
BOD	Can cause fish kills because of a lack of available oxygen; increases the toxicity of other pollutants, such as mercury. Has been associated with FGD wastewaters that use organic acids for enhanced SO2 removal in the scrubber.
Boron	Frequently observed in high concentrations in coal combustion wastewater; leachate into groundwater has exceeded state drinking water standards; human exposure to high concentrations can cause nausea, vomiting, and diarrhea. Can be toxic to vegetation.
Cadmium	Elevated levels are characteristic of coal combustion wastewater-impacted systems; organisms with elevated levels have exhibited tissue damage and organ abnormalities.
Chlorides	Sometimes observed at high concentrations in coal combustion wastewater (dependent on FGD system practices); elevated levels observed in fish with liver and blood abnormalities.
Chromium	Elevated levels have been observed in groundwater receiving coal combustion wastewater leachate; invertebrates with elevated levels require more energy to support their metabolism and therefore exhibit diminished growth.
Copper	Coal combustion wastewater can contain high levels; invertebrates with elevated levels require more energy to support their metabolism and therefore exhibit diminished growth.
Iron	Leachate from impoundments has caused elevated concentrations in nearby surface water; biota with elevated levels have exhibited sublethal effects including metabolic changes and abnormalities of the liver and kidneys.
Lead	Concentrations in coal combustion wastewater are elevated initially, but lead settles out quickly; leachate has caused groundwater to exceed state drinking water standards. Human exposure to high concentrations of lead in drinking water can cause serious damage to the brain, kidneys, nervous system, and red blood cells.
Manganese	Coal combustion wastewater leachate has caused elevated concentrations in nearby groundwater and surface water; biota with elevated levels have exhibited sublethal effects including metabolic changes and abnormalities of the liver and kidneys.
Mercury	Biota with elevated levels have exhibited sublethal effects including metabolic changes and abnormalities of the liver and kidneys; can convert into methylmercury, increasing the potential for bioaccumulation; human exposure at levels above the MCL for relatively short periods of time can result in kidney damage.
Nitrogen	Frequently observed at elevated levels in coal combustion wastewater; may cause eutrophication of aquatic environments.
pH	Acidic conditions are often observed in coal combustion wastewater; acidic conditions may cause other coal combustion wastewater constituents to dissolve, increasing the fate and transport potential of pollutants and increasing the potential for bioaccumulation in aquatic organisms.
Phosphorus	Frequently observed at elevated levels in coal combustion wastewater; may cause eutrophication of aquatic environments.
Selenium	Frequently observed at high concentrations in coal combustion wastewater; readily bioaccumulates; elevated concentrations have caused fish kills and numerous sublethal effects (*e.g.*, increased metabolic rates, decreased growth rates, reproductive failure) to aquatic and terrestrial organisms. Short term exposure at levels above the MCL can cause hair and fingernail changes; damage to the peripheral nervous system; fatigue and irritability in humans. Long term exposure can result in damage to the kidney, liver, and nervous and circulatory systems.

Table I-1: Common Coal-combustion Wastewater Pollutants (adapted from EPA, 2009d)

Compound	Potential Environmental Concern
Total Dissolved Solids	High levels are frequently observed in coal combustion wastewater; elevated levels can be a stress on aquatic organisms with potential toxic effects; elevated levels can have impacts on agriculture & wetlands.
Zinc	Frequently observed at elevated concentrations in coal combustion wastewater; biota with elevated levels have exhibited sublethal effects such as requiring more energy to support their metabolism and therefore exhibiting diminished growth, and abnormalities of the liver and kidneys.

Table I-2: T&E Species with Habitat Overlapping Waterbodies Affected by Steam Electric Power Plants

Species	Species Group	Vulnerability
Acipenser brevirostrum	Fishes	High
Acipenser medirostris	Fishes	High
Acipenser oxyrinchus desotoi	Fishes	High
Acipenser oxyrinchus oxyrinchus	Fishes	High
Alasmidonta heterodon	Clams	High
Alasmidonta raveneliana	Clams	High
Amblema neislerii	Clams	High
Amblyopsis rosae	Fishes	High
Ambystoma bishopi	Amphibians	Moderate
Ambystoma cingulatum	Amphibians	Moderate
Ambystoma macrodactylum	Amphibians	Moderate
Ambystoma tigrinum	Amphibians	Moderate
Ammodramus savannarum floridanus	Birds	Low
Anguispira picta	Snails	Low
Antrobia culveri	Snails	High
Antrolana lira	Crustaceans	High
Aphelocoma coerulescens	Birds	Low
Athearnia anthonyi	Snails	High
Batrisodes texanus	Insects	Low
Batrisodes venyivi	Insects	Low
Boloria acrocnema	Insects	Low
Brachylagus idahoensis	Mammals	Low
Brachyramphus marmoratus	Birds	Moderate
Brychius hungerfordi	Insects	High
Bufo houstonensis	Amphibians	Moderate
Cambarus aculabrum	Crustaceans	High
Campeloma decampi	Snails	High
Campephilus principalis	Birds	Low
Canis lupus	Mammals	Low
Canis rufus	Mammals	Moderate
Charadrius melodus	Birds	Moderate
Cicindela dorsalis dorsalis	Insects	Moderate
Cicindela nevadica lincolniana	Insects	Moderate
Cicindela puritana	Insects	Moderate

Table I-2: T&E Species with Habitat Overlapping Waterbodies Affected by Steam Electric Power Plants

Species	Species Group	Vulnerability
Cicurina baronia	Arachnids	Low
Cicurina madla	Arachnids	Low
Cicurina venii	Arachnids	Low
Cicurina vespera	Arachnids	Low
Corynorhinus (=Plecotus) townsendii ingens	Mammals	Low
Corynorhinus (=Plecotus) townsendii virginianus	Mammals	Low
Cryptobranchus alleganiensis	Amphibians	High
Cyprinella caerulea	Fishes	High
Cyprogenia stegaria	Clams	High
Dendroica chrysoparia	Birds	Low
Dendroica kirtlandii	Birds	Low
Discus macclintocki	Snails	Low
Dromus dromas	Clams	High
Drymarchon corais couperi	Reptiles	Low
Elimia crenatella	Snails	High
Elliptio chipolaensis	Clams	High
Elliptio spinosa	Clams	High
Elliptio steinstansana	Clams	High
Elliptoideus sloatianus	Clams	High
Enhydra lutris nereis	Mammals	Moderate
Epioblasma brevidens	Clams	High
Epioblasma capsaeformis	Clams	High
Epioblasma florentina curtisii	Clams	High
Epioblasma florentina florentina	Clams	High
Epioblasma florentina walkeri	Clams	High
Epioblasma florentina walkeri (=E. walkeri)	Clams	High
Epioblasma metastriata	Clams	High
Epioblasma obliquata obliquata	Clams	High
Epioblasma obliquata perobliqua	Clams	High
Epioblasma othcaloogensis	Clams	High
Epioblasma torulosa rangiana	Clams	High
Epioblasma torulosa torulosa	Clams	High
Epioblasma turgidula	Clams	High
Etheostoma chermocki	Fishes	High
Etheostoma chienense	Fishes	High
Etheostoma etowahae	Fishes	High
Etheostoma fonticola	Fishes	High
Etheostoma nianguae	Fishes	High
Etheostoma nuchale	Fishes	High
Etheostoma phytophilum	Fishes	High
Etheostoma scotti	Fishes	High
Etheostoma sellare	Fishes	High
Eubalaena glacialis	Mammals	Low
Eurycea nana	Amphibians	High

Table I-2: T&E Species with Habitat Overlapping Waterbodies Affected by Steam Electric Power Plants

Species	Species Group	Vulnerability
Fusconaia cor	Clams	High
Fusconaia cuneolus	Clams	High
Gambusia georgei	Fishes	High
Gammarus acherondytes	Crustaceans	Moderate
Glaucomys sabrinus coloratus	Mammals	Low
Glaucomys sabrinus fuscus	Mammals	Low
Gopherus polyphemus	Reptiles	Low
Graptemys flavimaculata	Reptiles	High
Graptemys oculifera	Reptiles	High
Grus americana	Birds	Moderate
Grus canadensis pulla	Birds	Moderate
Hemistena lata	Clams	High
Heraclides aristodemus ponceanus	Insects	Low
Herpailurus (=Felis) yagouaroundi cacomitli	Mammals	Low
Hesperia leonardus montana	Insects	Low
Heterelmis comalensis	Insects	High
Juturnia kosteri	Snails	Low
Lampsilis abrupta	Clams	High
Lampsilis altilis	Clams	High
Lampsilis higginsii	Clams	High
Lampsilis perovalis	Clams	High
Lampsilis subangulata	Clams	High
Lampsilis virescens	Clams	High
Lasmigona decorata	Clams	High
Leopardus (=Felis) pardalis	Mammals	Low
Leopardus (=Felis) wiedii	Mammals	Low
Leptodea leptodon	Clams	High
Leptonycteris nivalis	Mammals	Low
Leptoxis ampla	Snails	High
Leptoxis foremani	Snails	High
Leptoxis plicata	Snails	High
Leptoxis taeniata	Snails	High
Lepyrium showalteri	Snails	High
Lioplax cyclostomaformis	Snails	High
Lycaeides melissa samuelis	Insects	Low
Lynx canadensis	Mammals	Low
Margaritifera hembeli	Clams	High
Medionidus acutissimus	Clams	High
Medionidus parvulus	Clams	High
Medionidus penicillatus	Clams	High
Medionidus simpsonianus	Clams	High
Mesodon clarki nantahala	Snails	Low
Mesodon magazinensis	Snails	Low
Microhexura montivaga	Arachnids	Low

Table I-2: T&E Species with Habitat Overlapping Waterbodies Affected by Steam Electric Power Plants

Species	Species Group	Vulnerability
Microtus pennsylvanicus dukecampbelli	Mammals	Moderate
Mustela nigripes	Mammals	Low
Mycteria americana	Birds	Moderate
Myotis grisescens	Mammals	Moderate
Neoleptoneta microps	Arachnids	Low
Neonympha mitchellii francisci	Insects	Low
Neonympha mitchellii mitchellii	Insects	Low
Neotoma floridana smalli	Mammals	Low
Nicrophorus americanus	Insects	Low
Notropis cahabae	Fishes	High
Noturus crypticus	Fishes	High
Noturus placidus	Fishes	High
Obovaria retusa	Clams	High
Odocoileus virginianus clavium	Mammals	Moderate
Odocoileus virginianus leucurus	Mammals	Moderate
Oncorhynchus clarkii stomias	Clams	High
Oncorhynchus clarkii stomias	Fishes	High
Oncorhynchus kisutch	Fishes	High
Orcinus orca	Mammals	Low
Orthalicus reses (not incl. nesodryas)	Snails	Low
Palaemonias alabamae	Crustaceans	Moderate
Palaemonias ganteri	Crustaceans	Moderate
Panthera onca	Mammals	Low
Pegias fabula	Clams	High
Percina antesella	Fishes	High
Percina aurolineata	Fishes	High
Percina rex	Fishes	High
Percina tanasi	Fishes	High
Peromyscus gossypinus allapaticola	Mammals	Low
Peromyscus polionotus ammobates	Mammals	Low
Peromyscus polionotus niveiventris	Mammals	Low
Peromyscus polionotus phasma	Mammals	Low
Phoebastria (=Diomedea) albatrus	Birds	Low
Phoxinus cumberlandensis	Fishes	High
Picoides borealis	Birds	Low
Plethobasus cicatricosus	Clams	High
Plethobasus cooperianus	Clams	High
Plethodon nettingi	Amphibians	Low
Pleurobema clava	Clams	High
Pleurobema collina	Clams	High
Pleurobema curtum	Clams	High
Pleurobema decisum	Clams	High
Pleurobema furvum	Clams	High
Pleurobema georgianum	Clams	High

Table I-2: T&E Species with Habitat Overlapping Waterbodies Affected by Steam Electric Power Plants

Species	Species Group	Vulnerability
Pleurobema hanleyianum	Clams	High
Pleurobema marshalli	Clams	High
Pleurobema perovatum	Clams	High
Pleurobema plenum	Clams	High
Pleurobema pyriforme	Clams	High
Pleurobema taitianum	Clams	High
Pleurocera foremani	Snails	High
Polyborus plancus audubonii	Birds	Low
Polygyriscus virginianus	Snails	Low
Potamilus capax	Clams	High
Potamilus inflatus	Clams	High
Pseudemys alabamensis	Reptiles	High
Ptychobranchus greenii	Clams	High
Ptychocheilus lucius	Fishes	High
Puma (=Felis) concolor coryi	Mammals	Low
Pyrgulopsis (=Marstonia) pachyta	Snails	High
Pyrgulopsis neomexicana	Snails	High
Pyrgulopsis ogmorhaphe	Snails	High
Pyrgulopsis roswellensis	Snails	Low
Quadrula fragosa	Clams	High
Quadrula intermedia	Clams	High
Quadrula sparsa	Clams	High
Quadrula stapes	Clams	High
Rangifer tarandus caribou	Mammals	Low
Rhadine exilis	Insects	Low
Rhadine infernalis	Insects	Low
Rhadine persephone	Insects	Low
Rhinichthys osculus thermalis	Clams	High
Salvelinus confluentus	Fishes	High
Scaphirhynchus albus	Fishes	High
Scaphirhynchus suttkusi	Fishes	High
Sciurus niger cinereus	Mammals	Low
Somatochlora hineana	Insects	High
Sterna antillarum	Birds	High
Sternotherus depressus	Reptiles	High
Strix occidentalis caurina	Birds	Low
Strix occidentalis lucida	Birds	Low
Stygobromus (=Stygonectes) pecki	Crustaceans	High
Stygoparnus comalensis	Insects	Low
Succinea chittenangoensis	Snails	Low
Sylvilagus palustris hefneri	Mammals	High
Tartarocreagris texana	Arachnids	Low
Texamaurops reddelli	Insects	Low
Texella cokendolpheri	Arachnids	Low

Table I-2: T&E Species with Habitat Overlapping Waterbodies Affected by Steam Electric Power Plants

Species	Species Group	Vulnerability
Texella reddelli	Arachnids	Low
Texella reyesi	Arachnids	Low
Toxolasma cylindrellus	Clams	High
Trichechus manatus	Mammals	Low
Triodopsis platysayoides	Snails	Low
Tryonia alamosae	Snails	High
Tulotoma magnifica	Snails	High
Tympanuchus cupido attwateri	Birds	Low
Typhlomolge rathbuni	Amphibians	High
Ursus americanus luteolus	Mammals	Low
Vermivora bachmanii	Birds	Moderate
Villosa trabalis	Clams	High
Xyrauchen texanus	Fishes	High
Zapus hudsonius preblei	Mammals	Low

Appendix J. Supporting Data for Impoundment Release Analysis

Table J-1: Historical Releases from EPA Survey (U.S. EPA, 2012d)

Facility	State	Release Year	Unit Height (feet)	Storage Capacity (ac-ft)	Category	Gallons Released	Capacity Factor	Release	Description
Meredosia Power Station	IL	2006	24	700	Big	500	0%	other	2006 - less than 500 gallons spilled from the Fly Ash Pond
Chesterfield Power Station	VA	2005	19	740	Big		U	other	2005 unusual discharge
Cliffside Power Station	NC	2005	38		Big		U	other	10/7/2005 the Cliffside Steam Station experienced a significant localized flood event. The floodwaters from the Suck Creek entered into the retired Units 1-4 ash basin, topped the top of the dam and washed away part of the basin's dike. Notifications were
Bowen Power Station	GA	2002	45	3676	Big		U	other	7/28/02 sink hole; 11 cubic yards of ash sediment reached creek.
Bowen Power Station	GA	2008	45	3676	Big		U	other	9/9/08 Stack Failure. Approximately 40 tons of ash left plant property and flowed to near by residential properties and approximately 2 tons of ash reached Euharlee Creek
Harllee Branch Power Station	GA	2000	83	1050	Big	35000	0%	other	discharge of slurry 12/1/00
R. M. Schahfer Power Station	IN	1998	4	48	Small		U	other	no details March 1998
Sherburne County Power Station	MN	2007	57	6198	Big	600	0%	other	600 Gal spill May 2007
Sherburne County Power Station	MN	2008	41	620	Big	8000	0%	other	Spring 2008, the piping used to transmit the fine fraction of the bottom ash from hydraulic dredging of the bottom ash pond broke and approximately 8000 gallons of water and as was discharged over the Bottom Ash Pond embankment to the gro

Table J-1: Historical Releases from EPA Survey (U.S. EPA, 2012d)

Facility	State	Release Year	Unit Height (feet)	Storage Capacity (ac-ft)	Category	Gallons Released	Capacity Factor	Release	Description
Dave Johnston Power Station	WY	2009	0	3	Small	14400	1%	other	Jan 2009 - 14,400 gallons of process water overflowed the canal
Naughton Power Station	WY		56	3370	Big	9249802	1%	other	55,000 cu. Yds of fly ash was spilled outside the pond boundries
PPL Martins Creek Power Station	PA	2005	43	1085	Big	1E+08	28%	other	2005 - Fly Ash spill (100 Million Gal) estimated 10 acres
Colstrip Steam Electric Station	MT	2003	25	245	Big	2700	0%	other	3/18/03 spill +/- 2700
Colstrip Steam Electric Station	MT	1995	88	4370	Big	100	0%	other	10/11/95 small spill +/- 100 gallons C Cell
Colstrip Steam Electric Station	MT	2000	88	4370	Big	50	0%	other	8/29/00 small spill +/- 50 gallons C Cell
Colstrip Steam Electric Station	MT	2006	88	4370	Big	2000	0%	other	2/1/06 hole in HDPE liner C Cell +/- 2000 gallons
Roxboro Power Station	NC	2008	37.5	53	Big		U	wall breach	2008 Pond Breach
W. H. Weatherspoon Power Station	NC	2001	28	1375	Big		U	other	Breach of an internal dike 2001
Winyah Power Station	SC	2008	30	1700	Big		U	other	2/14/08 Release of wastewater - seal failure
Johnsonville Power Station	TN	2004	30	2702	Big		U	other	Reported release of small quantity of ceneospheres on 03/27/2004 when discharge structure was disturbed during maintenance.
Kingston Power Station	TN	2003	50	8907	Big		U	other	11/07/2003 an ash release occurred to land from slough in the Dredge Cell embankment.
Kingston Power Station	TN	2006	50	8907	Big		U	other	11/01/2006 an ash release occurred to land from slough in the Dredge Cell embankment.

Table J-1: Historical Releases from EPA Survey (U.S. EPA, 2012d)

Facility	State	Release Year	Unit Height (feet)	Storage Capacity (ac-ft)	Category	Gallons Released	Capacity Factor	Release	Description
Kingston Power Station	TN	2008	50	8907	Big	1.1E+09	38%	wall breach	A release into the Emory River occurred on 12/22/2008 from the Dredge Cell embankment failure. No reports found of releases from the Main Ash Pond or S
Widows Creek Power Station	AL	2008	115	11709	Big		U	other	Reported release of small quantity of ceneospheres 01/30/2008.
Widows Creek Power Station	AL	2004	115	11709	Big		U	other	Reported release of small quantity of ceneosperes 12/10/2004 due to intense precipitation.
Widows Creek Power Station	AL	2009	150	10961	Big		U	other	An abandoned decant weir in Pond 2B failed on 01/09/2009
Eagle Valley Generating Station	IN	2008	38	415	Big	30000000	22%	wall breach	1 levee breache (1/30/2008)- State notified. 30 million gallons spill.
Eagle Valley Generating Station	IN	2007	28	415	Big	30000000	22%	wall breach	1 levee breache (2/14/2007)- State notified. 30 million gallons spill.
Limestone Electric Generating Station	TX	2000	0	50	Small	500	0%	other	May 19, 2000: Approximately 500 gallons of water was discharged resulting from a severe rainfall event. The pH of the discharge was 8.5 su, TSS was 88 mg/1 and Selenium was <0.010 mg/1. The discharge ultimately made its way to Lynn Creek. Event was repor
LaCygne Generating Station	KS	2007	45	9298	Big		U	other	July 2007 Due to unusual rainfall events
LaCygne Generating Station	KS	2007	45	9298	Big		U	other	Sept 2007 Due to unusual rainfall events
LaCygne Generating Station	KS	2009	45	9298	Big		U	other	May 2009- Due to unusual rainfall events
Riverside Generating Station	IA	2002	15	140	Big		U	other	April 14, 2002- Caused by Mississippi River flooding, fixed using drilled grout

Table J-1: Historical Releases from EPA Survey (U.S. EPA, 2012d)

Facility	State	Release Year	Unit Height (feet)	Storage Capacity (ac-ft)	Category	Gallons Released	Capacity Factor	Release	Description
Interstate Power & Light Co - M.L. Kapp Generating Station	IA	2009	10	2	Small		U	other	3/13/2009, IPL reported to the Iowa DNR an unpermitted release of water from this pond at a location which sealed the pond from a previous discharge channel. This water leakage was immediately repaired on 3/13/2009.
PSCo Comanche Station	CO	2007	0	12	Small	2500	0%	other	April 9, 2007- between 2,000-3,000 gallons spilled from a broken pipe
PSCo Valmont Station	CO	2008	0	16	Small	4204.455	0%	other	Feb 14, 2008 - 25 cu yd spill of bottom ash slurry

Table J-2: 137 NRD Settlements Documented by Israel for 1967 to 2013 (Israel 2006; 2013)

Row	State	Original NRD Amount	Year	Updated NRD Amount	Case	Notes	Included or Excluded	Reason for Exclusion
1	AL	$491,976	2006	$596,000	Shelby County Train Derailment	soybean spill leading to damage of aquatic life (fish, mussels, and snails)	Included	
2	AL	$1,000,000,000	2011	$1,081,352,000	Deepwater Horizon	oil spill in Gulf of Mexico	Excluded	Ocean
		$600,000,000	2013	$600,000,000			Excluded	Ocean
3	AK	$644,017	1997	$1,257,000	M/V Kuroshima	oil spill along coastline	Excluded	Ocean
4	AK	$1,000,000,000	1989	$2,968,963,000	Exxon Valdez	Exxon Valdez	Excluded	Ocean
5	AZ	$7,000,000	2013*	$7,000,000	ASARCO LLC	three historic mining sites	Excluded	CERCLA
6	AZ	$6,800,000	2012	$7,031,000	Freeport-McMoRan Corp Morenci Mine	hazardous substance release	Included	
7	AR	$2,000,000	1987	$6,898,000	Vertac Chemical Corporation Superfund Site	dioxin release from herbicide/pesticide plant	Excluded	CERCLA
8	CA	$16,300,000	1990	$45,789,000	American Trader Oil Spill	biological injury (effects on fish and birds) from a 416,598 gallon crude oil spill	Excluded	Ocean

Table J-2: 137 NRD Settlements Documented by Israel for 1967 to 2013 (Israel 2006; 2013)

Row	State	Original NRD Amount	Year	Updated NRD Amount	Case	Notes	Included or Excluded	Reason for Exclusion
9	CA	$14,000,000	2001	$22,133,000	Cantara Loop/ Dunsmuir Chemical Spill	spill of 19,000 gallons of an herbicide which damaged habitat and fish	Included	
10	CA	$30,000,000	2005	$38,481,000	Montrose Chemical	long-time accidental and purposeful discharges of DDT	Excluded	CERCLA
11	CA	$32,300,000	2007	$37,469,000	Cosco Busan Oil Spill	spill of 53,000 gallons of bunker fuel	Excluded	Ocean
12	CA	$5,400,000	1986	$19,761,000	Apex Houston Oil Spill	spill of 25,800 gallons of crude oil, killing 10,577 birds	Excluded	Ocean
13	CA	$10,800,000	1988	$34,538,000	Shell/Martinez Oil Spill	release of 400,000 gallons of crude oil into creek	Included	
14	CA	$2,700,000	1991	$7,346,000	Exxon Mobil/Santa Clara River Oil Spill	spill of 74,000 gallons of crude oil	Included	
15	CA	$1,400,000	1992	$3,596,000	Avila I Oil Spill	spill of 24,200 gallons of crude oil into Pacific Ocean	Excluded	Ocean
16	CA	$1,400,000	1993	$3,419,000	McGrath Oil Spill	release of 87,150 gallons of crude oil into McGrath Lake and the Pacific Ocean	Excluded	Ocean
17	CA	$7,100,000	1994	$16,318,000	ARCO/Santa Clara River Oil Spill	release of 190,000 gallons of crude oil into 16 miles of river	Included	
18	CA	$3,625,000	1996	$7,517,000	SS Cape Mohican Oil Spill	96,000 gallons of intermediate fuel oil released, with 40,000 gallons spilling into San Francisco Bay	Excluded	Ocean bay
19	CA	$4,820,000	1997	$9,405,000	M/V Kure/Humboldt Bay Oil Spill	bunker fuel oil spill killing birds and affecting saltmarsh, mudflats, kayaking, camping, surfing	Excluded	Ocean bay
20	CA	$1,900,000	1997	$3,707,000	Torch/Platform Irene Oil Spill	oil release into ocean, killing 700 birds, affecting sandy and rocky shoreline habitat	Excluded	Ocean
21	CA	$3,900,000	1998	$7,208,000	T/V Command Oil Spill	3,000 gallons of intermediate bunker oil discharged, damaging birds, shoreline habitat, recreational beach use	Excluded	Ocean

Table J-2: 137 NRD Settlements Documented by Israel for 1967 to 2013 (Israel 2006; 2013)

Row	State	Original NRD Amount	Year	Updated NRD Amount	Case	Notes	Included or Excluded	Reason for Exclusion
22	CA	$6,710,000	1999	$11,661,000	M/V Stuvyesant/Humboldt Oil Spill	2,000 gallons of intermediate fuel oil spilled into Pacific Ocean, killing 2,405 birds, damaging coastal beaches, shrimp, fish, and beach use	Excluded	Ocean
23	CA	$358,000	2000	$584,000	East Walker River Oil Spill	3,600 gallons of fuel oil spilled, impacting 15 miles of river	Included	
24	CA	$6,000,000	2000	$9,795,000	Avila II Oil Contamination	numerous pipeline leaks caused underground plume of oil products	Excluded	Groundwater only
25	CA	$1,150,000	2004	$1,573,000	Kinder-Morgan/Suisun Marsh Oil Spill	spill of 70,000 gallons of diesel into marsh	Excluded	Ocean
26	CA	$950,000	2013*	$950,000	Searles Valley Minerals/Searles Lake (Trona)	Hypersaline industrial wastewater discharged into large ponds	Included	
27	CA	$9,000,000	2013*	$9,000,000	Guadalupe Oil Field Contamination	pipeline leaks causing 80 plumes of diluent	Excluded	Ocean
28	CA	$9,000,000	2013*	$9,000,000	Iron Mountain Mine CERCLA Site	acid mine drainage over many decades	Excluded	CERCLA
29	CA	$6,750,000	2013*	$6,750,000	New Almaden Mine CERCLA Site	release of mercury in Guadalupe River watershed and south San Francisco Bay	Excluded	CERCLA
30	CA	$2,850,000	2013*	$2,850,000	Chevron/Castro	oil and mercury dischargers contaminating intertidal and sub-tidal mudflats	Included	
31	CA	$850,000	2009	$990,000	Dubai Star/San Francisco Bay Spill	400 gallons of intermediate fuel oil spilled, affecting shoreline, birds, human uses	Excluded	Ocean
32	CA	$22,700,000	2007	$26,333,000	S.S. Jacob Luckenbach Oil Spill	457,000 gallons of fuel released from a sunken ship, killing 51,569 birds between 1990 to 2003 and sea otters	Excluded	Ocean
33	CO	$194,000,000	2009	$226,019,000	California Gulch Site	superfund site with surface water and habitat remediation needs	Excluded	CERCLA

Table J-2: 137 NRD Settlements Documented by Israel for 1967 to 2013 (Israel 2006; 2013)

Row	State	Original NRD Amount	Year	Updated NRD Amount	Case	Notes	Included or Excluded	Reason for Exclusion
34	CO	$27,500,000	1992	$70,639,000	Rocky Mountain Arsenal	former weapons and chemicals manufacturing site	Excluded	CERCLA
35	CO	$10,000,000	1994	$22,983,000	Rocky Flats	former nuclear weapons manufacturer with plutonium, uranium, volatile organic compounds, metals, radionuclide materials, nitrates, and asbestos contamination	Excluded	CERCLA
36	CT	$15,000,000	1977	$120,787,000	Housatonic and Connecticut Rivers	PCB contamination from longtime discharges from a power plant	Excluded	
37	CT	$2,700,000	1967	$52,632,000	Quinnipiac River Basin	settlement funds to replace lost drinking water source from a landfill	Excluded	CERCLA
38	DE	$27,500,000	2010	$30,881,000	Athos I	discharge of 265,000 gallons into Delaware River and tributaries	Included	
39	FL	$3,100,000	1999	$5,387,000	Tampa Bay Oil Spill	362,000 gallons of fuel oil and other petroleum products, damaging beaches of shellfish beds	Excluded	Ocean
40	FL	$1,200,000	2006*	$1,455,000	Sapp Battery	metal contaminations in soil, surface water, groundwater, and wetlands from battery salvage	Excluded	
41	FL	$77,000	2013*	$77,000	Whitehouse Oil Pits Superfund Site	assessment costs and restoration of a wetland	Excluded	CERCLA
42	FL	$3,600,000	1997	$7,025,000	Alafia River	discharge of 50 million gallons of process water from a phosphogypsum stack breach	Included	
43	GA	$11,800,000	2006	$14,303,000	R.J. Schlumberger	PCB contamination	Excluded	CERCLA
44	HI	$5,800,000	2013	$5,800,000	M/V Cape Flattery	oil spill damaging 20 acres of coral reef, fish, algae, sea urchins, and other reef animals	Excluded	Ocean
45	ID	$498,500,000	2009	$580,775,000	Bunker Hill Mining Superfund Site	100 million tons of mining wastes in a river system; wildlife habitat damage, poisoning of birds and other wildlife	Excluded	CERCLA

Table J-2: 137 NRD Settlements Documented by Israel for 1967 to 2013 (Israel 2006; 2013)

Row	State	Original NRD Amount	Year	Updated NRD Amount	Case	Notes	Included or Excluded	Reason for Exclusion
46	ID	$60,000,000	1995	$131,504,000	Blackbird Mine Superfund Site	mining damage to surface water and wildlife (Chinook salmon)	Excluded	CERCLA
47	IL	$1,843,000	2011	$1,993,000	Former Indian Refinery	damages from various contaminants to groundwater, surface water, soils, and adjacent properties	Included	
48	IL	$450,000	2007	$522,000	Saline Branch and Salt Fork River	2 fish kills from sudden ammonia releases	Included	
49	IL	$263,000	2001	$416,000	Marathon Oil Company	numerous spills of crude oil and refined petroleum products impacting 29 counties	Included	
50	IL	$154,648	2001	$244,000	Vesuvius USA Corporation	spill of an industrial chemical into 3 tributaries of the Embarras River	Included	
51	IL	$105,000	2013*	$105,000	Williams Pipeline Company	pipeline leak of 10,000 gallons of gasoline and diesel oil into tributary of Salt Creek	Included	
52	IN	$86,000,000	1998	$158,936,000	Grand Calumet	dredging after PCB, oil, benzene, cyanide, and heavy metal contamination from Stell manufacturer, plus restoration of habitat	Excluded	CERCLA
53	IN	$6,250,000	2000	$10,203,000	White River	excessive chemical discharges killing 4.6 million fish; note that the settlement was for $14 million, $6.25 million of which was for NRD	Included	
54	IN	$600,000	2000	$979,000	American Chemical Services	discharge of chemicals from storage drums	Included	
55	IN	$31,309	1985	$121,000	I. Jones Recycling, Inc.	hazardous waste release	Included	
56	IN	$200,000	2009	$233,000	Lakeland Disposal Landfill	waste leakage into groundwater, surface water, and sediments	Included	
57	IN	$597,000	1999	$1,037,000	Waste Inc. Landfill	liquid waste drainage into aquifer, creek, and surrounding wetlands	Included	

Table J-2: 137 NRD Settlements Documented by Israel for 1967 to 2013 (Israel 2006; 2013)

Row	State	Original NRD Amount	Year	Updated NRD Amount	Case	Notes	Included or Excluded	Reason for Exclusion
58	KS	$1,200,000	2008	$1,369,000	Cherokee County Superfund Site	runoff from zinc and lead mine tailings that entered local streams and contaminated groundwater	Excluded	CERCLA
59	KY	$2,500,000	2007	$2,900,000	Russellville Plant	PCB pollution in groundwater, streams, and rivers	Included	
60	LA	$750,000	2011	$811,000	Calcasieu Estuary and Bayou Verdine	release of hazardous substances to soil and water, impacting assorted benthos and other marine resources	Excluded	CERCLA
61	ME	$1,000,000	1996	$2,074,000	Julie N Oil Spill	Oil spill; 130 acres of habitat enhancement/acquisition	Included	
62	ME	$125,000	1994	$287,000	F. O'Connor Superfund Site	groundwater damage from PCBs and solvents	Excluded	CERCLA
63	ME	$930,000	1997	$1,815,000	Maine Yankee	petroleum, solvents, and radiological materials from nuclear power plant	Included	
64	ME	$160,440	2013*	$160,000	S.D. Warren Facility	waste from manufacture of coated paper which contaminated groundwater	Excluded	Groundwater only
65	MD	$2,700,000	2000	$4,408,000	PEPCO Spill	oil spill; restoration of wetlands, oyster beds, waterfowl nesting areas, and terrapin habitat	Included	
66	MD	$507,300	2007	$588,000	Spectron, Inc. Superfund Site	contamination and oil from site which migrated to Little Elk Creek	Excluded	CERCLA
67	MA	$20,200,000	1992	$51,888,000	AVX/New Bedford Harbor	water column, sediments, shellfish, birds, anadromous fish, recreational fishing, beach usage	Excluded	CERCLA
68	MA	$1,353,000	1993	$3,304,000	Charles George Landfill	landfill pollution, gases, leachate, contamination, migratory birds, fish	Included	
69	MA	$157,000	1995	$344,000	PSC Resources	groundwater and wetlands	Included	
70	MA	$3,100,000	1998	$5,729,000	Nyanza/ Sudbury River	surface water (riverine habitat), wetlands, fisheries, other wildlife, recreational use	Included	

Table J-2: 137 NRD Settlements Documented by Israel for 1967 to 2013 (Israel 2006; 2013)

Row	State	Original NRD Amount	Year	Updated NRD Amount	Case	Notes	Included or Excluded	Reason for Exclusion
71	MA	$30,000	1999	$52,000	Hallmark/ Mystic River	surface water (riverine habitat), recreational use	Included	
72	MA	$19,700,000	2000	$32,159,000	General Electric/ Housatonic River	ground and surface water, nesting habitats, recreational fishing and boating, various aquatic organisms and birds	Included	
73	MA	$30,000	2003	$44,000	Sulfuric Acid Spill/ North River	Various aquatic resources, aquatic fish, amphibians, invertebrates, and plant species	Included	
74	MA	$500,000	2004	$684,000	Coal Tar Deposits/ CT River	various aquatic resources, endangered species	Included	
75	MA	$142,000	2004	$194,000	Posavina Oil Spill/ Chelsea Creek	coastal land and habitat, salt water vegetation, migratory birds, fish	Excluded	Ocean
76	MA	$1,300,000	2007	$1,508,000	Textron Systems Corporation/Mass Military Reservation Superfund Site	groundwater	Excluded	CERCLA
77	MA	$312,500	2008	$357,000	Global/Irving Chelsea Creek Oil Spill	surface water, shoreline, wetlands, salt marsh	Included	
78	MA	$747,000	2010	$839,000	Rubchinuk Landfill Site	community use	Included	
79	MA	$1,650,000	2010	$1,853,000	Sutton Brook Disposal Area Superfund Site	groundwater, biological resources and their habitats	Excluded	CERCLA
80	MA	$1,094,000	2011	$1,183,000	Blackburn and Union Privileges Superfund Site	groundwater, biological resources and their habitats	Excluded	CERCLA
81	MA	$6,076,000	2011	$6,570,000	Bouchard B-120 Buzzards Bay Oil Spill	aquatic and shoreline, ram island shoreline, recreation and shellfish, and piping plovers	Excluded	Ocean bay
82	MA	$875,000	2012	$905,000	GM Assembly Plant in Framingham	streambed, banks, and surrounding wetlands; birds, wildlife, and benthic macroinvertebrates	Included	
83	MA	$4,250,000	2012	$4,395,000	Pharmacia Corp./Bayer CropScience Superfund Site	wetland, river, and lake habitat; fish, turtles, amphibians, and migratory birds	Excluded	CERCLA

Table J-2: 137 NRD Settlements Documented by Israel for 1967 to 2013 (Israel 2006; 2013)

Row	State	Original NRD Amount	Year	Updated NRD Amount	Case	Notes	Included or Excluded	Reason for Exclusion
84	MI	$807,490	1989	$2,397,000	Verona Well Field	groundwater contamination from leaking solvents	Excluded	Groundwater only
85	MI	$26,200,000	1998	$48,420,000	Saginaw River and Bay	PCB release into Saginaw River	Included	
86	MS	$3,000,000	1999	$5,214,000	Genesis Pipeline Spill	crude oil spill; surface water, sediments, shoreline habitat, wildlife	Included	
87	MO	$49,000	2013*	$49,000	Cominco/Halliburton	seven lead and copper metal concentrate spill sites	Included	
88	MO	$20,100,000	2009	$23,417,000	Newton County Mine Tailings Superfund Site	releases of cadmium, lead, and zinc to groundwater, surface water, sediments, aquatic and terrestrial plants and organisms, aquatic mammals, fish, aquatic and terrestrial invertebrates, and migratory birds	Excluded	CERCLA
89	MO	$41,200,000	2009	$48,000,000	Southeast Missouri Lead Mining District	four mine sites impacting surface water, geological resources, groundwater, and aquatic and terrestrial biota	Excluded	CERCLA
90	MT	$138,000,000	1999	$239,823,000	Atlantic Richfield Company	decades of mining and mineral processing releasing hazardous substances	Included	
		$169,000,000	2008	$192,848,000			Included	
		$5,900,000	2009	$6,874,000			Included	
91	MT	$37,000,000	2008	$42,221,000	Mike Horse Dam	Dam failure in 1975 due to heavy rains. Contaminated tailings were washed into the Beartrap Creek and the Upper Blackfoot River	Included	
92	MT	$1,600,000	2012	$1,654,000	Silvertip Pipeline Oil Spill	63,000 gallons of oil spilled into Yellowstone River	Included	
93	NV	$859,528	2013	$860,000	Rio Tinto Mine	abandoned copper mine waste disposal in Mill Creek	Included	
94	NH	$1,500,000	2005	$1,924,000	Coakley Landfille Superfund Site	contamination of wetlands with various pollutants; restoration of 338 acres of degraded saltmarsh	Excluded	CERCLA

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Row	State	Original NRD Amount	Year	Updated NRD Amount	Case	Notes	Included or Excluded	Reason for Exclusion
95	NJ	$20,000	2013*	$20,000	In re Former Owens-Illinois Closure Site	contamination of groundwater	Excluded	Groundwater only
96	NJ	$40,462,000	2013*	$40,462,000	In re Phelps Dodge Site	hazardous waste discharge into groundwater	Excluded	Groundwater only
97	NJ	$150,000	2009	$175,000	In re Jimmie's Raceway Service Station	contamination of soil and groundwater from gas station	Excluded	Groundwater only
98	NJ	$3,218,700	2009	$3,750,000	Combe Fill South Landfill Superfund Site	contamination of groundwater and nearby brook	Excluded	CERCLA
99	NM	$1,000,000	2000	$1,632,000	Sparton Technology Site	damage to groundwater from discarded solvents and plating wastes	Excluded	Groundwater only
100	NM	$1,100,000	2006*	$1,333,000	Albuquerque ATSF Site	railroad tie treating plant; damages to groundwater and wildlife habitat	Included	
101	NM	$13,000,000	2010	$14,598,000	Freeport McMoRan	damages to groundwater, wildlife, and wildlife habitat	Excluded	Groundwater only
		$5,500,000	2012	$5,687,000			Included	
102	NM	$30,000	2004	$41,000	SOHIO L-Bar Facility	uranium tailings which contaminated groundwater	Excluded	Groundwater only
103	NM	$7,500,000	2006	$9,091,000	State of New Mexico v General Electric Company et al.	contaminated groundwater from a Superfund site	Excluded	CERCLA
104	NY	$20,300,000	2013	$20,300,000	St Lawrence River in Massena	PCB contamination in a river	Excluded	
105	NY	$12,000,000	2006	$14,545,000	Lake Ontario System	release of dangerous chemicals into Lake Ontario System	Included	
106	OH	$13,750,000	2008	$15,690,000	Fernald Uranium Products	uranium products (over 1,000 acres) damaging groundwater	Excluded	CERCLA
107	OH	$5,500,000	2012	$5,687,000	Ashtabula River	remediation of contaminated sediment	Excluded	CERCLA
108	OH	$2,040,000	2006	$2,473,000	Ohio River	restoration of damage to mussels, fish, and snails from contamination from a metals company	Included	

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Row	State	Original NRD Amount	Year	Updated NRD Amount	Case	Notes	Included or Excluded	Reason for Exclusion
109	OK	$300,000	2007	$348,000	Double Eagle Superfund Site	contamination of groundwater by hazardous waste	Excluded	CERCLA
110	OR	$50,000	2013*	$50,000	Whitaker Slough Cleanup	contamination of Whitaker Slough by electroplating wastewater	Included	
111	OR	$100,000	2013*	$100,000	Johnson Lake	overflow from settling ponds and stormwater discharges	Included	
112	OR	$300,000	2009	$350,000	Union Carbide Site	Claims related to waste from carbide and ferroallow processing contaminating the Columbia Slough.	Included	
113	PA	$21,000,000	2009	$24,466,000	Palmerton Zinc Superfund Site	injuries to aquatic and terrestrial resources from zinc and other metals	Excluded	CERCLA
114	PA	$7,350,000	2006	$8,909,000	Sinnemahoning Creek Watershed	spill of sodium hydroxide from train derailment, damaging several waterbodies	Included	
115	RI	$8,000,000	2013*	$8,000,000	North Cape Oil Spill	828,000 gallons of home heating oil spilled, killing at least 9 million lobsters, thousands of birds, and millions of clams, crabs, and fish	Excluded	Ocean
116	RI	$1,415,000	2005	$1,815,000	Calf Pasture Point and Allen Harbor Landfill	discharge of chemical wastes (chlorinated hydrocarbons and VOCs) into groundwater	Excluded	Groundwater only
117	RI	$6,000,000	2011	$6,488,000	Buzzard's Bay	oil spill injuring shoreline and aquatic resources, piping plovers, and recreational uses	Excluded	Ocean bay
118	RI	$750,000	2013	$750,000	Davis Liquid Waste Superfund Site	contamination of groundwater	Excluded	CERCLA
119	SC	$121,000	2012	$125,000	Cooper River/Charleston Harbo	release of 12,500 gallons of fuel oil affecting shoreline habitats, sediments, migratory birds, shellfish beds, and recreational shrimp baiting	Included	

Table J-2: 137 NRD Settlements Documented by Israel for 1967 to 2013 (Israel 2006; 2013)

Row	State	Original NRD Amount	Year	Updated NRD Amount	Case	Notes	Included or Excluded	Reason for Exclusion
120	SD	$4,000,000	2006*	$4,848,000	South Dakota v Homestake Mining Company	damage to surface and groundwater from metals (from mining)	Included	
121	TN	$543,203	2002	$831,000	Obed Wild and Scenic River Site	oil spill and fire in tributaries of the Obed Wild and Scenic River	Included	
122	TN	$50,000	2010	$56,000	U.S. Department of Energy's Oak Ridge Reservation	damages to fishing from release of hazardous substances and radioactive compounds	Included	
123	TX	$3,120,000	2012	$3,226,000	Malone Service Co. Disposal Facility	hazardous waste material that contaminated groundwater and migrated to Galveston Bay	Excluded	CERC LA
124	UT	$37,000,000	1995	$81,094,000	Southwest Jordan Valley	$28 million in restoration of groundwater, damaged by historic mining, $9 in compensation	Included	
125	UT	$2,580,000	2007	$2,993,000	Ensign-Bickford Trojan Facility	discharges from explosives manufacturing facility into groundwater (3 mile plume)	Excluded	Groundwater only
126	UT	$3,500,000	2011	$3,785,000	Red Butte Creek Oil Spill	pipeline rupture releasing oil into creek and other waters	Included	
127	VA	$3,700,000	2003	$5,399,000	Tazewell County Spill	1,300 gallons of a rubber accelerant, which damaged endangered species of freshwater mussels	Included	
128	VA	$2,500,000	2001	$3,952,000	Powell River	six million gallons of coal slurry release to river watershed (20 miles downstream), impacting fish, endangered mussels, aquatic habitat, bats, and migratory birds	Included	
129	WA	$5,000,000	2006*	$6,061,000	Elliot Bay/ Duwamish River	habitat development and restoration after damage from sewer discharges	Included	
130	WA	$5,500,000	2005	$7,055,000	Skykomish Facility	discharge of diesel fueil which leaked to water table	Included	

Table J-2: 137 NRD Settlements Documented by Israel for 1967 to 2013 (Israel 2006; 2013)

Row	State	Original NRD Amount	Year	Updated NRD Amount	Case	Notes	Included or Excluded	Reason for Exclusion
131	WA	$9,000,000	1994	$20,685,000	Tenyo Maru	release of 354,800 gallones of fuel oil and 97,800 gallons of diesel fuel, affecting coastal waters and shorelines and killing 4,300 seabirds	Excluded	Ocean
132	WA	$512,857	2008	$585,000	Crystal Mountan Emergency Generation Facility	release of 18,200 gallons of diesel fuel into creek	Included	
133	WV	$2,040,000	2006	$2,473,000	Ohio River	restoration of native freshwater mussels, snails, and fish in Ohio River	Included	
134	WV	$500,000	2009	$583,000	Consol Energy/Dunkard Creek	discharge of mining wastewater containing chloride, resulting in an algae bloom that killed thousands of fish, mussels, and amphibians	Included	
135	WI	$35,000,000	2013*	$35,000,000	Fox River/Green Bay	contamination from PCB and other discharges from paper mills	Excluded	CERCLA
136	WI	$1,900,000	2012	$1,965,000	Ashland Lakefront	contaminated sediments	Included	
137	WY	$50,000	2013*	$50,000	Gasoline Spill	restocking a surface water after a fish kills from a gasoline spill	Included	

Appendix K. Methodology for Benefits from Avoided Dredging Costs

The following subsections describe EPA's methodology for estimating sediment dredging benefits by applying the unit dredging costs to changes in the volume of sediment deposited to navigable waterways and reservoirs under the five regulatory options. The section is organized as follows:

- Review and analysis of historical dredging data including dredging locations, intervals, and costs;
- Estimation of sediment deposition to dredged waterways and reservoirs using SPARROW; and
- Estimation of dredging costs savings under regulatory options based on changes in sediment deposition and unit cost of dredging.

EPA notes that the methodology presented here focuses solely on avoided dredging costs based on the volume of sediment. Due to data limitations, the analysis does not quantify environmental benefits of reducing the frequency of maintenance dredging, nor does it account for potentially lower costs associated with disposing of dredged material spoils due to reduced discharge of toxic metals.

K.1 Review and Analysis of Historical Dredging Data

EPA used data from the United States Army Corps of Engineers (USACE) Dredging Information System (USACE, 2013) to analyze baseline navigational dredging activity and to estimate the cost per cubic yard of sediment dredged. The system catalogs all USACE dredging contracts and USACE-conducted dredging jobs from 1998 to 2012, including the location of dredging activities, start and stop dates, the volume of sediment dredged, and the cost of the dredging job. The system does not report separate cost components, but costs typically include (Sohngen & Rausch, 1998):

- Cost of dredging sediment from the waterway's channel bed and loading onto a boat,
- Cost of transporting dredged material to a disposal facility, and
- Cost of confining or disposing of the dredged material.

EPA reviewed available information about sediment removal methods at existing U.S. reservoirs. The review indicated that dredging is a practical and common approach to sediment removal in existing reservoirs. With the exception of draining a reservoir and excavating settled sediment (which is typically more expensive and less common than dredging), dredging is the only feasible option for sediment removal in many reservoirs (Morris and Fan, 1997). Other methods to counteract sedimentation or reclaim capacity at existing reservoirs include:

- *Sediment routing* – a group of techniques that allow sediment-laden water to pass around or through a reservoir without allowing the sediment to settle, optimized to address sediment-laden flows from events such as storms and floods (Morris and Fan, 1997). EPA was not able to find any information on the prevalence or effectiveness of these techniques.[107]
- *Flushing* – the scouring of accumulated sediment from a reservoir by partially or fully draining it and allowing the erosive force of the draining water to carry sediment through and downstream of the reservoir. The practice does not appear to be very common in the United States as it creates

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[107] Including sediment pools during initial construction and maintaining these pools can also reduce sediment deposition (Crowder 1987).

extraordinarily high sediment concentrations downstream of the reservoir,[108] and the reservoir may still require dredging (Morris and Fan, 1997).

Theoretically, reductions in sediment loadings could delay the construction of new reservoir capacity and associated construction costs, including land for the reservoir itself, embankments, mitigation lands, appurtenances to the dam (if applicable), such as pump stations, and pipelines to connect the reservoir to the treatment plant or raw water users. In practice, it may not be feasible to construct new capacity in many cases due to space constraints or adverse ecological effects associated with reservoir construction. Furthermore, the ELG regulatory options result in only marginal changes in sediment deposition to existing reservoirs that are unlikely to be of sufficient magnitude to influence decision-making regarding capacity expansion.

Based on this review, EPA focused its benefits analysis for reservoirs on dredging over other capacity reclamation approaches due to the frequent use and broad feasibility of dredging. Given likely similarities in cost components for navigational dredging and reservoir dredging, EPA used regional estimates of cost per cubic yard of sediment dredged based on the USACE Dredging Information System as inputs for its analysis of avoided reservoir dredging costs. The Agency recognizes that dredging costs are highly variable and driven my factors including costs for dewatering sites, weather, topography, and characteristics of bottom sediments, and that at some sites dredging costs could exceed the costs of other alternatives, potentially including the unit cost of constructing new capacity.[109] EPA notes that the volume of sediment that can be dredged from reservoirs may also affected by the availability of funds or nearby disposal sites (Morris & Fan, 1997).

K.1.1 Dredging Location, Recurrence Interval, and Dredging Volumes

Each observation in the Dredging Information System corresponds to a given date range and location at which dredging occurred, referred to here as “dredging occurrence.” Many locations have multiple dredging occurrences because recurrent dredging is may be necessary to maintain navigability. EPA uses the term “dredging job” to refer to multiple dredging occurrences at the same location. For each dredging job, EPA identified:

- *The number of occurrences from 1998 to 2012*. EPA merged dredging occurrences at the same location that were less than 30 days apart because these may be continuations of the same dredging occurrence, rather than a new dredging occurrence. If determined to be a continuation of prior occurrence, EPA summed the volume of sediment dredged and costs of the records to generate a single observation in the database.
- *Average dredging volume from 1998 to 2012*. EPA divided the total quantity of sediment dredged for each job (single location) over the past 15 years by the number of occurrences of that job to calculate an average quantity of sediment dredged for an occurrence of that job. EPA assumed that this quantity of sediment would be dredged each time the job occurs in the future under the baseline scenario, and that it would be reduced due to the final ELGs

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[108] Concentration can sometimes exceed 1,000,000 mg/L and thus may require special permissions (Morris and Fan, 1997)

[109] Alan Plummer Associates (2005) compared the cost of dredging to the costs of constructing additional reservoir capacity for reservoirs in Texas and found that dredging unit costs are at least twice that of securing storage in new reservoirs. New reservoir costs are approximately $1 for each cubic yard of water stored in the conservation pool (2011$, updated based on the construction cost index), whereas dredging costs for large-sized dredging projects are approximately $2 per cubic yard (2011$, updated based on the construction cost index) and, depending on variability, could cost more than two times that amount.

- *The time elapsed between dredging occurrences*. EPA calculated an average frequency of recurrence for each dredging job in years by dividing 15 (the number of data years, 1998-2012) by the number of occurrences of that job.

The number of dredging jobs in the system varies by region, and is likely to be influenced by the size of the region, the number of navigable waterways, and their economic importance.

Where the USACE Dredging Information System did not contain cost or quantity of sediment dredged for a listed dredging occurrence, EPA estimated the missing information from other jobs. The Agency calculated 10th, 50th, and 90th percentile costs and quantity boundaries and used these to fill in all incomplete records in each EPA region. EPA used the 10th and 90th percentile cost and amount dredged estimates in the low and high total dredging cost estimates, respectively. The cost data were adjusted to 2013$ using the construction cost index.

K.1.2 Determining Affected Navigational Dredging Jobs and Unit Costs

For this analysis, EPA mapped each navigational dredging job with latitude-longitude coordinates to the nearest reach modeled in SPARROW (E2RF1 reaches), within a one-mile radius. For jobs for which latitude-longitude coordinates were not provided, EPA used alternate job location information such as the name of the job (usually the waterway dredged) and the USACE district that performed the job.[110] EPA excluded dredging jobs that are greater than 1 mile from a SPARROW reach from the analysis.[111]

This approach matched 29 unique dredging jobs and 98 dredging occurrences to analyzed E2RF1 reaches, equivalent to 0.8 percent of the dredging occurrences with coordinates reported in the Dredging Information System. The remaining 99 percent of occurrences were either greater than 1 mile from a modeled reach. *Table K-1* summarizes dredging jobs and recurrence intervals in the affected reaches. The recurrence interval ranges from 1 to 15 years across all affected reaches, with an average of 9.6 years.

Table K-2 summarizes the average cost of dredging. Costs vary considerably across affected reaches, from approximately $$1.59 per cubic yard at Establishment Bar in North Carolina to $28.08 per cubic yard at Bonum Creek in Virginia. The average unit cost of dredging for the entire coterminous United States is $$5.56 per cubic yard.

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[110] EPA reviewed to the data to identify cases where latitude-longitude coordinates appear to have been misreported based on district and reach information. Where possible, EPA populated missing coordinates by interpolating from other occurrences of the same dredging job.

[111] To identify the nearest reach segment, EPA used an unprojected version of the ERF 1.2 (Enhanced Reach File) from USGS. For this analysis, EPA researched latitude-longitude coordinates for jobs where they were not provided and linked them to Reach File Version 1.0 (RF1) reaches. Each latitude/longitude of interest was matched to the nearest point in the ERF 1.2 universe of points using a spherical model of the earth and a standard haversine distance formula. No reach types were excluded from consideration in the nearest reach calculation

Table K-1: Navigational Dredging Jobs and Recurrence Intervals from 1998 to 2012 within Affected Reaches

Number of Affected Dredging Jobs	Number of Recurring Jobs	Number of Single Occurrence Jobs	Average Interval for Single Occurrence and Recurring Jobs (years)	Average Interval for Recurring Jobs (years)
29	15	15	9.6	3.7

Note: Includes dredging jobs with latitude-longitude coordinates that could be mapped to affected E2RF1 reaches.

Source: Dredging Information System (USACE, 2013).

Table K-2: Historic Dredging Costs from 1998 to 2012 within Affected Reaches

Number of Affected Reaches	Total Sediment Removed (millions of cubic yards)	Total Cost (millions of 2013$)	Average Cost per cubic yard (2013$)
29	72.0	$754.0	$10.5

Note: Only includes jobs EPA was able to map to affected reaches.

Source: Dredging Information System (USACE, 2013).

K.1.3 Determining Reservoir Dredging Locations

EPA relied upon the "reservoir" flags within the E2RF1 dataset to identify reservoir locations. SPARROW models reservoirs as impoundments located on the main reach network. For the purposes of this analysis, EPA assumed, consistent with Crowder (1987), that all sediment entering reservoirs must be removed in order to maintain current water storage capacity.

K.2 Sediment Deposition in Navigable Waterways and Reservoirs

EPA estimated annual sediment deposition to waterways using sedimentation outputs from SPARROW. EPA assumed that all sediment deposited within historically dredged waterways will be dredged at some future point. Likewise, EPA assumes that all sediment deposited in the affected reaches with reservoirs will also be dredged.

As described in *Chapter 4*, the SPARROW outputs reflect changes in annual sediment deposition based on the changes in sediment loadings under the final ELGs. EPA assumed that reduced deposition starts in 2021, which is the midpoint of the period during which steam electric plants are expected to implement changes to meet the final rule limitations and standards.

K.3 Estimating Dredging Costs under Baseline and Regulatory Options

Benefits under the final ELGs are calculated for each year from 2021 to 2042 as the difference between baseline dredging costs and post-compliance dredging costs. Each waterway or reservoir will have unique benefits based on sediment deposition, dredging frequency, and the unit cost of dredging. Dredging costs only occur in years when the waterbody or reservoir is projected to be dredged.

K.3.1 Estimating Annualized Dredging Costs for Navigational Waterbodies

For each dredging job location, EPA assumes that future dredging occurrences will happen at the same frequency as in the past. The volume of sediment removed in each dredging occurrence is equal to the amount of sediment deposited in that reach since the prior occurrence at that job location. For example, if dredging occurs every two years at given job location, then the first analyzed occurrence project for the second year of the analysis period (2022). The volume of sediment dredged in that occurrence is the sum of sediment deposited in the current year and prior year (2021 and 2022). The dredging cost incurred in 2022 is the product of the cubic yards dredged and unit cost per cubic yard. By the end of the 2042, the reach will have been dredged ten times.

Equation J-1 presents the calculation of annual dredging costs for navigational waterways for the baseline and regulatory options. EPA discounted the costs following the analytic framework described in *Chapter 1*.

Equation J-1

$$AV = \sum^{I} \left(\frac{Q_{b,t} \times (1-R) \times C}{(1+d)^{t-2015}}\right) \times \left(\frac{d \times (1+d)^{n}}{(1+d)^{n+1}-1}\right)$$

Where:

AV = Annualized value

I = The index for the dredging occurrence. The number of occurrences is based on the total number of periods (22) and the recurrence interval for the dredging job. The recurrence interval is calculated by dividing 15 years by the number of occurrences of the job in the USACE dredging data.

Q_b = Cubic yards of dredged materials under the baseline scenario in a given year t

T = Year of dredging occurrence

R = Percentage of cubic yards of dredge material remaining under the regulatory scenario relative to baseline

C = Cost per cubic yard of sediment dredged for the dredging job location (2013$)

D = Annual discount rate. EPA used both 3 percent and 7 percent, in accordance with OMB guidance (Office of Management and Budget, 2003)

N = Number of periods for annualization (24 years for this benefits analysis)

EPA conducted a sensitivity analysis for navigational dredging by varying assumptions for projected future dredging occurrence, generating low, medium, and high estimates for navigational dredging:

- For medium and high estimates, EPA assumed that single occurrence dredging jobs occur once every 15 years (*i.e.*, the number of data years). Single occurrence jobs are dropped from future projections for the low estimate.
- For low and medium estimates, dredging is interpreted as occurring at the end of each interval (*i.e.*, 2022 in the example described above). For the high estimate, EPA assumes that dredging occurs at the beginning of the interval, rather than the end (*e.g.*, 2021). This second approach tends to generate greater discounted benefits because jobs occur sooner and are discounted less.
- EPA varied costs for jobs lacking actual cost values and dredging volumes in the Dredging Information System. EPA assigned 10th, 50th, and 90th percentile costs for low, mean, and high estimates, respectively.
- For the mean estimate, EPA assumed a minimum recurrence interval of 90 days. Occurrences that began less than 90 days from the end of the prior occurrence at the same job location were considered

to be continuation, and combined in the data. EPA used intervals of 30 and 180 days for the low and high estimates, respectively.

These assumptions are summarized in *Table K-3*.

Table K-3: Parameters Used in Sensitivity Analysis of Avoided Dredging Costs

Parameter Value	Treatment of Single Occurrences	Treatment of Interval	Percentile of Cost Estimates Used for Jobs Lacking Cost Data	Minimum Recurrence Interval
Low	Excluded	Start	10th Percentile	30 days
Mean	Included	End	50th Percentile	90 days
High	Included	End	90th Percentile	180 days

K.3.2 Estimating Annualized Dredging Costs for Reservoirs

The frequency of reservoir dredging is highly site-specific, depending on many factors including the average sediment concentration of the influent river or stream, the flow regime, the size of the reservoir and excess storage capacity, and any sediment routing practices. For this analysis, EPA chose a general frequency of reservoir dredging based on information presented by the USACE in a Final Dredged Material Management Plan and Environmental Impact Statement for reservoirs in Washington (USACE, 2002). The report states that "dredging cycles may vary from 2 to 10 years" (USACE, 2002, p. 66). EPA used these frequencies as high and low estimates and 6 years as a mean estimate. This approach provides a range of benefits estimates to account for uncertainty in the frequency of reservoir dredging.

EPA was unable to identify a comprehensive source of cost data for reservoir dredging.[112] The Agency used the average unit cost of dredging from the analysis of USACE Dredging Information System Data grouped by EPA region. Because this cost is given per cubic yard, the sediment attenuation in reservoirs given by SPARROW will be converted from kilograms to cubic yards using a sediment density of 1.5 g/cm$_3$ (Hargrove 2007). This translates to a conversion of 1,147 kilograms per cubic yard. *Equation K-2* summarizes the calculation of annualized avoided costs for an affected reservoir. The total annualized avoided cost is the sum of annualized cost savings at all affected reservoirs.

Equation K-2: $AC_r = \sum^I \left[\frac{\frac{\left(Q_{r,b,t} - Q_{r,s,t}\right)}{1147} \times C}{(1+d)^{t-2014}}\right] \times \left[\frac{d \times (1+d)^n}{(1+d)^{d+1} - 1}\right]$

Where:

AC = Annualized avoided cost of dredging all sediment settling in reservoir r

r = Reservoir reach ID number

I = The assumed interval in years of reservoir dredging; varied between 2, 6, and 10

Qb = Quantity of sediment present at baseline (kg)

Qs = Quantity of sediment present under the regulatory option (kg)

1,147 = Number of kilograms per cubic yard of sediment

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[112] Some limited information on the costs of reservoir dredging is available in the literature. For example, Crowder (1987) provides a unit cost but provides not empirical basis for the estimate.

C = Regional average of historic dredging job cost per cubic yard, 1998-2012.
r = ELG regulatory option (Option A – Option E)
t = Year of the dredging occurrence
d = Annual discount rate. EPA used both 3 percent and 7 percent.
n = Number of periods for annualization (24 years for the benefits analysis)

K.4 Results

Benefits under each regulatory option are equal to avoided costs, calculated as the difference in total annualized dredging costs at baseline and under regulatory options. The subsections below summarize navigational dredging and reservoir dredging benefits.

K.4.1 Navigational Dredging Benefits

Table K-4 presents estimates of baseline sediment dredging from 2021 to 2042 and low, mean, and high cost estimates. Total baseline navigational dredging costs range from $ 36 thousands to $48 thousands per year, using a 3 percent discount rate, and between $29 to $42 thousands using a 7 percent discount rate. *Table K-5* presents estimated benefits for navigational dredging for the five regulatory options. Annualized benefits for Option D are less than one thousand, with both 3 and 7 percent discount rates.

Table K-4: Annualized Dredging Costs at Affected Reaches under the Baseline (Thousands of 2013$)

Total Sediment Dredged (millions cubic yards)			Costs at 3% discount rate (thousands of 2013$ per year)			Costs at 7% discount rate (thousands of 2013$ per year)		
Low	**Mean**	**High**	**Low**	**Mean**	**High**	**Low**	**Mean**	**High**
96.4	97.3	125.5	36.2	36.5	47.9	29.2	29.4	42.1

Source: EPA analysis, 2015.

Table K-5: Annualized Benefits from Reduced Dredging Costs (Thousands of 2013$)

Regulatory Option	Total Reduction in Sediment Dredged (Baseline – Option; cubic yards)			3% discount rate (thousands of 2013$ per year)			7% discount rate (thousands of 2013$ per year)		
	Low	**Mean**	**High**	**Low**	**Mean**	**High**	**Low**	**Mean**	**High**
Option A	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Option B	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Option C	763.8	819.6	2,606.4	0.4	0.4	0.9	0.3	0.3	0.9
Option D	1,496.7	1,735.0	6,648.3	0.8	0.8	2.2	0.6	0.6	2.0
Option E	3,122.7	3,361.5	8,530.1	1.5	1.5	3.0	1.1	1.2	2.7

Source: EPA analysis, 2015.

K.4.2 Reservoir Dredging Benefits

Table K-6 presents the total amount of sediment that is estimated to be dredged in 2021 from reservoirs, and the estimated annualized cost of dredging under the baseline scenario, including low, mean, and high estimates. Estimated dredging costs for the reservoirs range between $477.6 million and $577.8 million with a three percent discount rate and $344.4 million and $480.0 million with a seven percent discount rate under the baseline scenario.

Table K-6: Annualized Reservoir Dredging Costs under the Baseline (Millions 2013$)

Total Sediment Dredged (millions cubic yards) (2021-2042)			3% Discount Rate ($/year)			7% Discount Rate ($/year)		
Low	Mean	High	Low	Mean	High	Low	Mean	High
2,934.6	2,641.2	3,228.1	477.6	469.5	577.8	344.4	378.9	480.0

Source: EPA analysis, 2015.

The difference between the anticipated dredging costs under the baseline and a particular regulatory option represents the avoided costs of that regulatory option. *Table K-7* presents reductions in sedimentation and subsequent avoided costs from reduced reservoir dredging for each regulatory option, including low, mean, and high estimates under these regulatory options. Because the range of estimates is relatively small between the low and high estimates, the values presented below in the discussion below are mean estimates unless otherwise stated.

Avoided costs from a reduction in reservoir sedimentation vary depending on the regulatory option, the assumed frequency of reservoir dredging, and the discount rate. Annualized benefits for Option D are less than two thousand dollars with both 3 and 7 percent discount rates.

Table K-7: Total Annualized Benefits of Reduced Reservoir Dredging (2013$)

Regulatory Option	Total Reduction in Sediment Dredged (cubic yards) (2021-2040)[a]			3% Discount Rate (thousands of 2013$ per year)			7% Discount Rate thousands of 2013$ per year)		
	Low	Mean	High	Low	Mean	High	Low	Mean	High
Option A	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Option B	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Option C	8,106.0	7,295.4	8,916.6	1.6	1.6	2.0	1.2	1.3	1.6
Option D	9,624.1	8,661.7	10,586.5	1.9	1.9	2.3	1.4	1.5	1.9
Option E	11,114.0	10,002.6	12,225.4	2.2	2.2	2.7	1.6	1.8	2.2

Source: EPA analysis, 2015.

K.5 Limitations and Uncertainties

Table K-8 summarizes key uncertainties and limitations for the analysis of sediment dredging benefits. Note that the SPARROW model used to estimate sediment deposition also has a number of limitations, described in Environmental Impact and Benefits Assessment for Final Effluent Guidelines and Standards for the Construction and Development Category (U.S. EPA 2009c).

Table K-8. Limitations and Uncertainties in the Analysis of Avoided Costs of Navigational Waterway Dredging

Issue	Effect on Benefits Estimate	Notes
Lack of standardized job names in USACE Database	Underestimate	The USACE dredging database identifies dredging jobs by name, usually the name of the dredged waterbody, but lacks standardized naming conventions. It is possible that the same waterbody is dredged under different job names. For the low cost estimates, this may result in the exclusion of dredging job names that only appear once in the database, but in fact were carried out in the same waterbodies as a differently named job. This effect would tend to underestimate benefits in EPA's low estimates.
Analysis restricted to jobs reported in USACE Database for 1998 to 2012	Underestimate	The USACE database is limited to USACE dredging contracts from 1998 to 2012. It does not capture dredging jobs contracted by other organizations or jobs occurring before 1998 or after 2012.
Lack of latitude and longitude data in USACE Database	Underestimate	Many dredging occurrences lack or have incomplete latitude coordinates. As a result, EPA was only able to map about 71 percent of all dredging occurrences with records in the data. EPA did not attempt to use other methods, such as Google Earth, to map dredging locations to the E2RF1 reaches due to resource constraints. The result is a downward bias in benefits estimates because the analysis excludes some dredging jobs that may benefit under the final rule.
Do not estimate benefits to waterways that are not dredged	Underestimate	EPA's dredging analysis is limited to navigable waterways that have been dredged in the past and reservoirs flagged within the E2RF1 dataset. Other waterbodies not identified by these data could require dredging in the future and benefit from sediment reductions under the proposed rule. Thus, EPA's estimates may be underestimated.
Omission of reservoirs located off E2RF1 channels	Underestimate	The benefits analysis for modeled watersheds explicitly omits any reservoirs that are not located on the E2RF1 network. The omission of other reservoirs is likely to bias estimated reservoir dredging benefits downward.
Lack of site specific data on sediment density	Uncertain	EPA used a single sediment density estimate to convert between sediment mass and volume. This may reduce the accuracy of resulting benefits estimates because sediment density is related soil type in the area and is not uniform. The direction of this potential bias is uncertain.
Lack of data on the frequency of reservoir dredging and the amount of sediment dredged	Uncertain	There is significant uncertainty as to the types of reservoirs that are dredged and the unit cost of dredging. The appropriateness of benefits estimates for reservoirs is conditional on assumption that water storage volume will be maintained. Actual benefits may diverge from estimates presented here if reservoirs take response actions other than dredging to address sediment loads.
Assumption that excess sediment is removed from reservoirs by dredging rather than building new reservoir capacity	Uncertain	EPA's analysis of reservoir benefits assumes that all excess sediment is removed by dredging. Reservoir capacity could be replaced with new reservoirs in some cases. The unit cost of constructing new reservoirs may be higher or lower than dredging depending on site-specific characteristics.

Table K-8. Limitations and Uncertainties in the Analysis of Avoided Costs of Navigational Waterway Dredging

Issue	Effect on Benefits Estimate	Notes
Omission of natural water storage facilities from the analysis	Underestimate	The SPARROW model does not take into account sediment build-up in natural water storage facilities such as glacial lakes and ponds. Any activity to mitigate sedimentation in these waterbodies is not included in this benefits analysis. This may bias benefits estimates downward.